STUDIES ON ADULT, JUVENILE, AND LARVAL FISHES OF THE GAMBIA RIVER, WEST AFRICA, 1983-1984

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Dedicated to

KARL F. LAGLER

Teacher, Mentor, and Friend
To All of Us

ACKNOWLEDGMENTS

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CONTENTS

GENERAL INTRODUCTION

BACKGROUND

The growing human population in most areas of the world has placed ever increasing demands upon our global resources. This situation is particularly apparent in West Africa where recent drought has reduced agricultural and livestock production, resulting in increasingly widespread famine. Included among suggested responses to this problem are accelerated use of existing resources, and development of additional processes of resource exploitation. Regarding "development" of resource exploitation, three general stages of activity may be designated: identification of potential resources; evaluation of procedures, impacts, costs/benefits, etc.; and implementation of exploitation processes. The Gambia River Basin Development Organization (OMVG) and its member states, Guinea, Guinea-Biseau, Senegal, and The Gambia, are charged with directing development activities within the Gambia River basin. Currently under consideration is construction of a series of dams on the Gambia, Liti, and Koulountou rivers to create a saltwater barrier, impound water for irrigation, and generate hydroelectric power, respectively. Construction sites are contemplated near the following locations: Balingho, The Gambia; Kekreti, Senegal; and Kougoa-Foulbe, Kouya, and Kankakoura, Guinea.

Under a contract with the United States Agency for International Development (USAID), The University of Michigan (Ann Arbor, Michigan) in collaboration with Harza Engineering Company (Chicago, Illinois) has undertaken a set of environmental and socioeconomic studies in the Gambia River basin. The purpose of these studies is to assist the Organisation pour la Mise en Valeur du Fleuve Gambie (OMVG) and its member states, Guinea, Guinea-Biseau,

Senegal, and The Gambia, in (1) analysis of environmental and socioeconomic facets extant in the basin, and (2) project and prepare for changes that will occur in the basin during and after construction of the dams.

The University of Michigan studies in the Gambia River basin were divided into three phases as follows: Phase I - preparation and submission of a detailed project work plan; this phase was completed in March 1983 and the work plan (UM/GRBS 1983) was accepted by USAID and OMVG. Phase II - data collection and preliminary analysis of impacts and mitigation of proposed development activity; this phase was completed in December 1984. Phase III - preparation and submission of a final integrated report; this phase was completed in 1985.

The University of Michigan/Harza Engineering studies were divided into four study components or teams: Socioeconomics, River Resources, Wildlife/Vegetation, and Public Health. Following completion of field studies, analysis of data, and presentation of team findings and recommendations, an integrated analysis of results of these four studies is presented as a summary report. This integrated analysis describes environmental and socioeconomic conditions in the basin and provides an analytical tool for projection, evaluation, and recommendations regarding possible future development activities in the basin.

RIVER RESOURCE TEAM OBJECTIVES AND ORGANIZATION

Objectives of the overall river resource survey are discussed in detail in the project work plan (UM/GRBS 1983) and include: (1) catalogue, assemble, and review existing relevant literature and data from the Gambia River; (2) develop a preliminary understanding of the Gambia River system through a reconnaissance mission; (3) develop as complete an understanding of the

ecology of the Gambia River and estuary as possible; (4) develop a detailed understanding of the fishery (finfish and shellfish) dynamics of the Gambia River and estuary; (5) determine the importance of finfish and shellfish to the local economy; (6) project impacts of the salinity barrage and dams on the river and estuary; (7) recommend mitigative measures in response to projected ecological damage created by construction and operation of the salinity barrage and dams and; (8) offer recommendations regarding continuation of aquatic studies.

In accordance with these objectives, the River Resource Team was charged with evaluating the following features or variables within the aquatic environment: physical-chemical variables; planktonic biological variables; variables associated with aquatic macrophytes, mangroves, benthos, and shellfish; and variables associated with fish and fisheries.

Included with physical-chemical variables were: salinity, conductivity, temperature, suspended solids, sediment load, underwater light intensity, pH, alkalinity, dissolved nutrients (nitrogen, phosphorus, silicon), organic matter, and dissolved oxygen. Variables related to plankton included: chlorophyll, enumeration of phytoplankton and zooplankton species, and enumeration of bacterioplankton. Variables related to aquatic macrophytes, mangroves, benthos, and shellfish were addressed during general surveys. Included in the survey of fish were: species identification and enumeration; assessment of major species distribution, abundance, and migratory patterns; biomass (stock) estimates; catch composition analysis and statistical interpretations; and impact assessment on estuarine, coastal, and marine fisheries.

TEAM STUDY COMPONENTS

An important approach of the River Resource Team which determined the nature of the study was reliance on collection of new data. We believed that these data, combined with those amassed from relevant literature, would provide a more accurate understanding of the river system as it exists today. To facilitate the division of expertise and data collection process the team survey was divided into separate but interacting survey components as follows: physical-chemical studies; primary productivity studies; bacterioplankton studies; phytoplankton studies; zooplankton studies; shellfish and macrobenthos studies; and fish studies. In addition to the above, separate surveys were conducted by team consultants to assess river hydrology, mangrove ecology, and fishery economics in the basin. Data and findings of these various studies were integrated to obtain a composite understanding of river processes, ecology, and economics, and to project impacts and mitigative measures related to changes in the river and the basin. Data and findings of each study component within the overall team survey were presented in working documents and individual reports. Results and findings of these individual reports were reviewed and combined in an integrated team report which was used to satisfy previously stated team study objectives (Moll and Dorr 1985). The remainder of this general introductory section describes the objectives and format of this report on River Resource Team studies on fish of the Gambia River.

OBJECTIVES AND ORGANIZATION OF STUDIES ON FISH

To achieve both project and team objectives and conduct a credible research program on Gambia River fish, a goal and pursuant objectives were

defined for our studies on fish. Our goal was to achieve a basic understanding of the biological and ecological relationships of fishes within the river system, to combine this with knowledge of artisanal fishery targets and catch and the socioeconomics of these fisheries, and to analyze existing conditions, make projections, and suggest mitigative actions regarding fish and development activities in the Gambia River basin. The following objectives were established for our studies on fish:

1) To establish a data base and achieve a basic understanding of the relative abundance and distribution of major species and their spatial and temporal distribution, movements, feeding, growth, maturation, and spawning.
2) To establish a data base and achieve a preliminary understanding of the occurrence and relative abundance, spatial and temporal distribution, and movements of larval fish.
3) To describe basic biological processes and relationships among adult, juvenile, and larval fish and their environment.
4) To identify key phases of species life history and relationships with environmental factors that may be particularly sensitive to environmental perturbations.

The remainder of this report reflects efforts to accomplish these four objectives. The chapter on Experimental Design describes the analytical approach and sampling design of the study. Selection of study areas, sampling techniques, data processing, and statistical procedures are discussed in relation to study objectives and precepts of the Gambia River system.

The chapter on Adult and Juvenile Fish presents species accounts on adult and juvenile fish. The overall sampling effort, species identifications and

classification, ecological categorization and dominance of species, and general distribution of fish are presented in overview at the beginning of this chapter. This overview is followed by individual species accounts which address a variety of topics when supporting data were available. These topics include: abundance and distribution, length-frequency distribution, maturation, diet, and other aspects of life history.

The chapter on Larval Fish discusses data and findings on larval fish. Similar to the preceding section on adult and juvenile fish, our sampling effort, identification and classification, ecological categorization and dominance, and general distribution of larval fish are presented in overview at the beginning of the chapter. This is followed by individual accounts on species or other taxonomic categories of larvae which include discussion of the following points when supporting data were available: abundance and distribution, length-frequency distribution, ecology, and possible impacts of development.

The Fishery Economics chapter discusses the existing system, its economic status, and the implications of its development.

The General Discussion chapter examines the following topics: fish ecology, fish production, and monitoring, assessment, and management.

It is our hope that the data and findings contained in this report will form a database and understanding of Gambia River fish and fisheries, and document aspects of their life history, biology, ecology, and assessment. Also, we hope that it will aid future scientists and studies in their attempts to investigate, evaluate, and manage this and other river systems.

SYSTEM OVERVIEW

A sizeable body of literature exists on inland tropical water systems in Africa (Beadle 1981), fisheries ecology of floodplain rivers (Welcomme 1979), stock assessment of tropical fisheries (Saila and Roedel 1980), fisheries management in large rivers, and impacts of tropical reservoirs (Freeman 1974). In addition, case studies have been conducted on many large African rivers including the Nile, Niger, Zaire (Congo), and Zambezi and have been reviewed by Beadle (1981). Recently, development studies have been conducted on the major rivers immediately north (Senegal River) and south (Casamance River) of the Gambia River. With respect to fish of the Gambia River, studies have been conducted on their general biology (Svensson 1933; Johnels 1954), major species accounts (e.g., *Ethmalosa fimbriata* - Scheffers and Conand 1976, Charles-Dominique 1982), and the fisheries (Taylor-Thomas 1976, King 1979, Lesack and Drammeh 1980).

Floodplain rivers may be divided into two components - the floodplain and the main river channel. Each of these components may be further divided into sub-systems that might be equated with various habitats such as pelagic and benthic zones, inshore and offshore zones, etc. Identification and analysis of biological and ecological processes associated with these habitats formed an integral part of the experimental design.

Total production within a river system represents the composite of production among various trophic levels such as primary producers (algae and macrophytes), heterotrophic producers (bacteria), primary consumers (zooplankton, invertebrates), and secondary consumers (fish and other vertebrates). Generally speaking, production in the upper reaches of floodplain rivers is primarily dependent upon allochthonous inputs. In the lower reaches, both

nutrient inputs and total productivity are increased but the proportional contribution of autochthonous inputs is often greatly increased. The relative complexity of nutrient input and production in various parts of a floodplain river system could be debated, but the fact that this relationship differs in various regions of the river is unquestionable.

With respect to fish, species diversity, total production, and biomass are usually greatest in the lower reaches of a floodplain river. Also, floodplain production usually exceeds that of the main river channel by several orders of magnitude. The seasonal inundation of floodplain areas results in release of terrestrial nutrients and organic detritus such as nitrates, and seeds, leaves, and insects which serve to sharply increase system production. When rainfall is seasonal, as is often the situation in tropical river systems, nutrient and detrital inputs and river production are also seasonal and cyclic in nature (Welcomme 1979).

The Gambia River is located on the west side of the African continent between 11.5 and 13.5 degrees latitude and 12.5-17.0 degrees longitude and has a general east-to-west flow. It originates in the Fouta Djalon Mountains near Labe, Guinea, and flows north into eastern Senegal where it turns west and flows through The Gambia to the Atlantic Ocean. The river is about 1,100 km long and its vertical descent is about 1,200 m from headwaters to mouth.

The channel bottom is predominantly bedrock and river banks are steep, the result of extensive down-cutting through surrounding hills. Below the Guinean escarpment the river descends from about 400 m elevation to sea level near Banjul, The Gambia. However, maximum elevation in The Gambia is about 30 m and the river shows negligible slope in its Gambian reach. Consequently, from Kedougou to the Senegambian border the river is high-banked and slow-

running with only isolated riffle areas. Bank height at low water is about 6 m at the eastern border of The Gambia and falls to less than 1 m near Bansang, The Gambia, where distinct tidal effects occur. In its Gambian reach the river is entirely slow-running and interspersed by occasional areas of deep water. Depths typically range from 5 m to 25 m, although pools 35 m in depth were measured.

The geological structure of the Gambia River basin and consequent river morphology provide a water course that is essentially free of barriers, e.g., waterfalls or extensive shallows, to fish movements. Therefore, it is possible for fish to travel 900 km along the river, although we did not observe movements of this magnitude during our studies.

The Gambia River basin annually incurs two major hydrological regimes - wet and dry season. Historically, rains begin during March-April at the headwaters in the Fouta Djalon Mountains and spread north and west, reaching the western end of the river by May-June. Rains continue until October-November with the headwater region receiving more than 2,000 mm of rain annually and the lower reaches at least half that amount. However, during the last 20 years West Africa has experienced widespread and prolonged droughts because of reduced and irregular rainfall. During the 1980s, the droughts have been increasingly severe, with total 1983 rainfall the lowest recorded for the Senegambian region. This has resulted in a major impact to the annual hydrological regime of many West African rivers including the Gambia River (Fig. 1). Much of the floodplain area that was annually inundated prior to the 1960s is now permanently indurated. Our 1983 observations in traditional floodplain areas documented only minimal areas of standing fresh water. Also, floodplains in tidal reaches of the river were typically drained twice

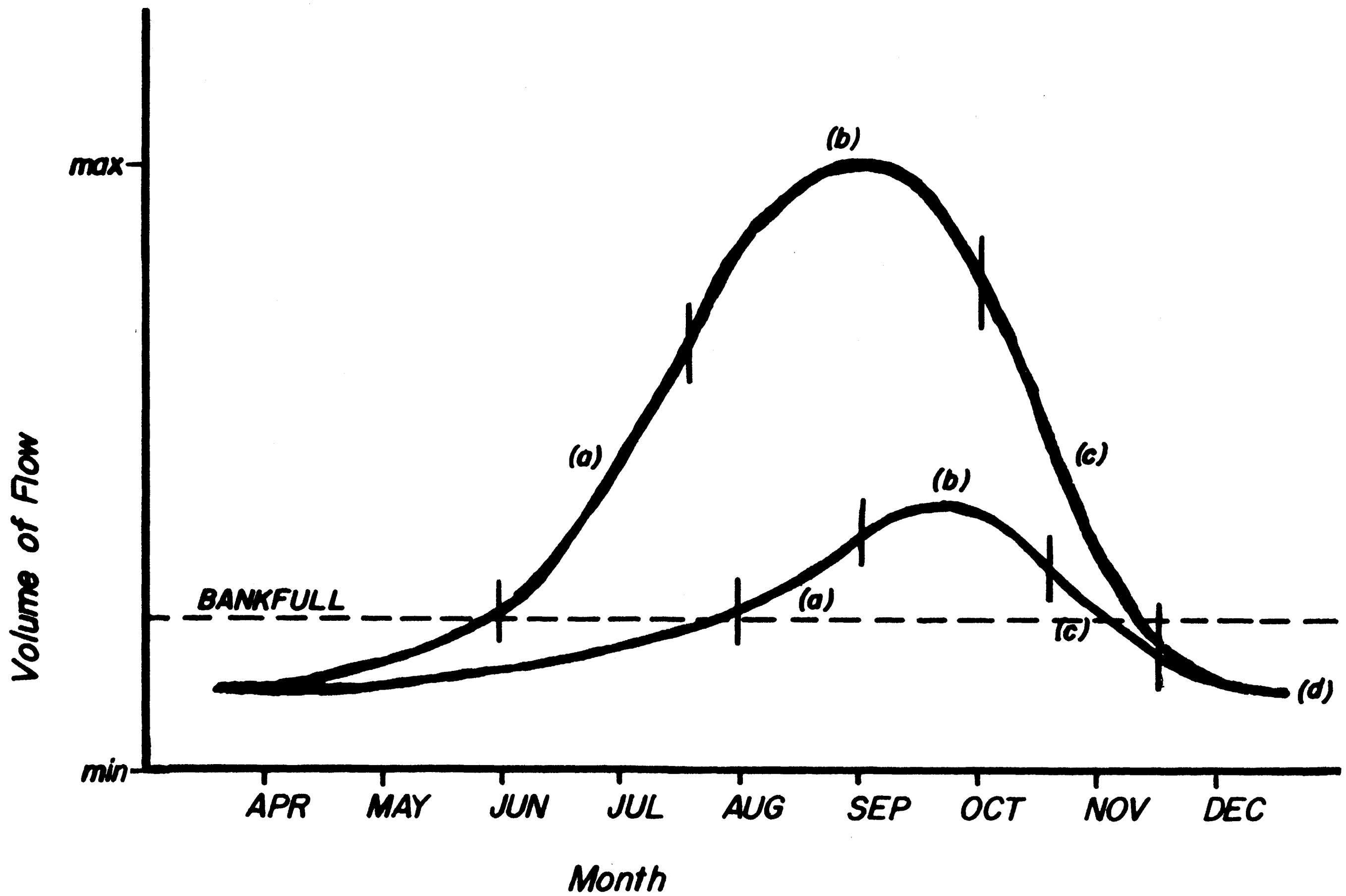


FIG. 1. General curve of flood rivers. Upper curve represents Gambia River regime in historical times; lower curve is typical of the past decade. Portions of the flood regime are indicated as (a) rising, (b) peak, (c) falling, (d) low water. Adopted from Welcomme (1979).

during the 24-hour period and exposed to air and solar radiation for varying lengths of time.

Without question, the recent reduction in rainfall and extent of floodplains has greatly altered the aquatic ecology of the region and reduced floodplain production. Total annual river system production is without doubt considerably less than it was 20-30 years ago and the contribution of the floodplains to that total is proportionately much less now. Therefore, ecological analysis of both existing conditions and projected impacts of basin development activities must consider the temporal and spatial alterations in river hydrology and productivity which have recently taken place. An additional caution is that much of the literature which describes pre-drought conditions in the Gambia River is now outdated.

In light of the preceding discussion, it is possible that changes in aquatic ecology and production as a result of the prolonged drought may in some respects rival those which might be incurred from river impoundments. Such a possibility should be considered when considering the merits and effects of development activities on the Gambia River. Paralleling observed and projected trends in aquatic production is the dependency of human populations on this resource and the extent to which this dependency has been forced to redistribute itself as the aquatic system has changed. If river impoundments were to increase or otherwise change current fish production, it will be necessary to project how these populations will respond to such changes in production.

In addition to the annual rains and river flood, two other major influences on the Gambia River are tidal effects and intrusion of saline waters.

We observed 1-m tides 300 km upriver and tidal effects were reported to extend as far as 500 km upriver, the entire length of the river in The Gambia. Vertical displacement decreases from 2 m near the river mouth proceeding inland.

During periods of low water, a minimal extent of river bank is cyclically exposed and inundated with the tides because the river is entirely contained within the main channel. However, during peak flooding, extensive areas of lowland or floodplain surrounding the lower reaches of the river are cyclically flooded and drained. We observed that most of the pre-drought floodplain area was tidal at best; much of these areas was not flooded at all, undoubtedly the result of drought and greatly reduced flood volumes. Additionally, the period of inundation was reduced from weeks to a few hours during high tide, which must have resulted in profound changes in the flood-plain communities and production. Such changes would include an overall reduction in river system fish production.

Lateral displacement of water during the tide cycle has been discussed but longitudinal displacement also occurred. We observed peak ebb flows of 5.5 km/hour. Given the approximate 6-hour ebb or flow period, maximum longitudinal displacement would not exceed 33 km during any one ebb or flood period. Considering the homogeneous morphometry of the river channel and the nonlinear nature of tidal flow rates, longitudinal displacements of 10-15 km are probably more realistic estimates. During peak flood, there was a net movement of water downstream, but during the low water period, longitudinal displacements of water appeared to be more of a stationary oscillatory movement. Finally, times of peak high and low water during the tide cycle did not coincide exactly with changes in flow direction. The discrepancy between

displacement (height) and flow (stream) are common in tidal systems such as rivers. We observed that, although the time of peak high or low water did not coincide with the change in tide stream direction in the main river channel, changes in tide stream direction in the bolons coincided closely with peak high and low water in the main river channel.

The second major oceanic influence on the Gambia River is intrusion of saline water. We identified three general water masses: marine (salinity >30 ppt), estuarine (salinity measurable to 30 ppt), and fresh water (no measurable salinity). Although the upstream distance of these various water masses varies with the seasonal discharge of fresh water, estuarine conditions exist all year within the confines of the river (Fig. 2). During peak flooding, the extent of the estuary is decreased because of the increased volume of fresh water that fills the river and reduces penetration of salt water. Although we were able to measure changes in salinity along the river course and establish longitudinal salinity gradients (Fig. 2), we were unable to detect significant vertical differences or the presence of a salinity wedge. In terms of tidal and salinity effects, the lower reaches of the Gambia River resemble an elongate ocean bay more closely than a river discharging fresh water directly into the ocean. This is largely the result of river channel gradients, morphometry, and hydrology.

Given the profound influence of the annual flood, tidal effects, and intrusion of saline water on the Gambia River, close attention was made to analysis of the influence of these factors on the abundance, distribution, biology, and ecology of fish in the river. Both the mechanism of effect and impact of changes on these factors is evaluated in this report.

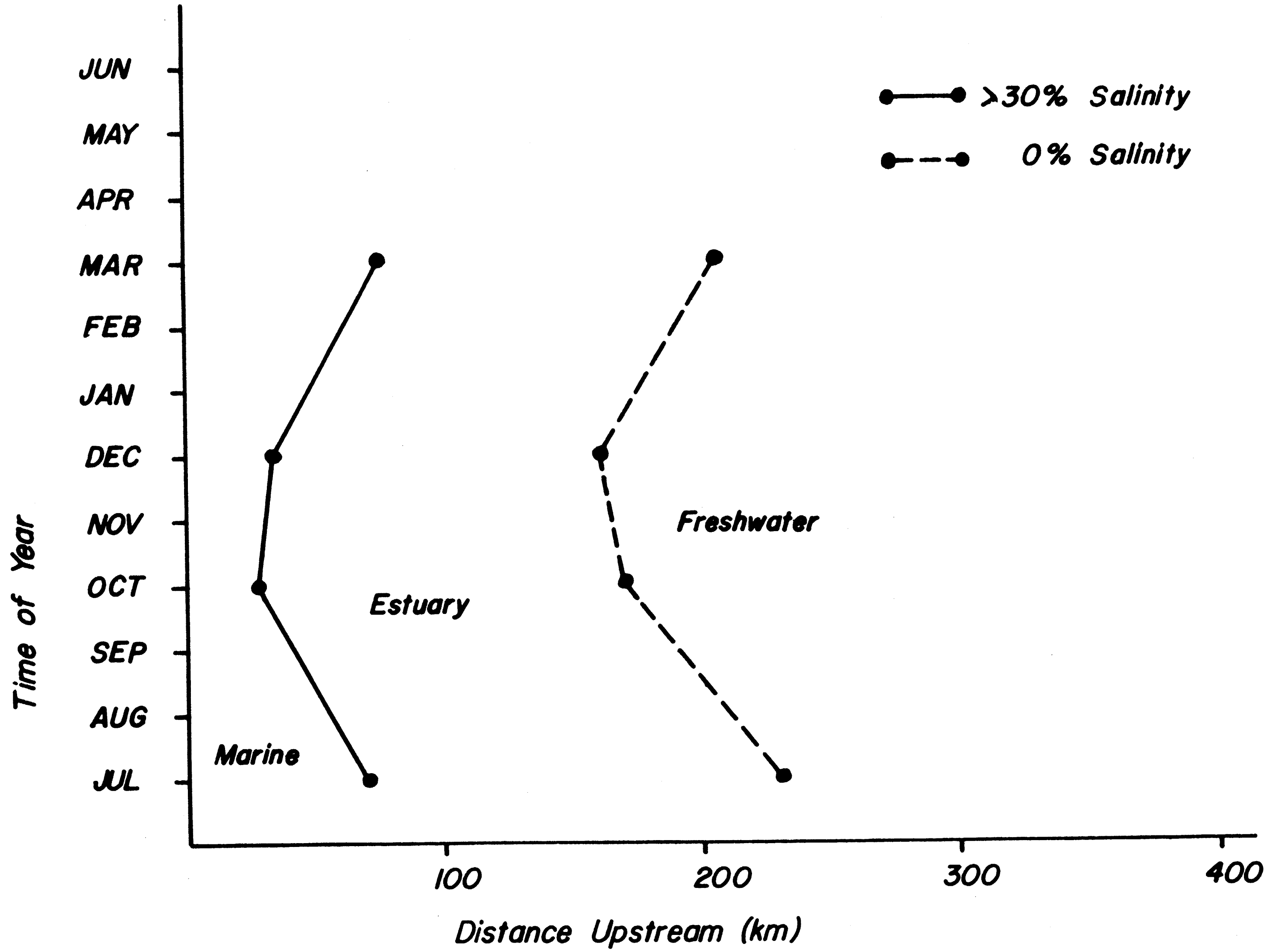


FIG. 2. Temporal and spatial variation in the extent of saline water extrusion into the Gambia River, West Africa.

EXPERIMENTAL DESIGN

GENERAL ANALYTICAL APPROACH

Several major concepts guided our analytical approach to studies on fish as well as other components of the Gambia River system. Our *a priori* evaluation of the Gambia River was that not only has this river been poorly studied, but that many of the tropical habitats present along the river are poorly understood on a global scale. As a consequence, we relied heavily on collection of new data to more adequately and exactly describe the river and predict changes caused by basin development.

Given the variety of habitats that exist along the river, we opted to select key study locations which were representative of various habitats and aquatic environments. Therefore, a large baseline data base was established, analysis of which generated several products vital to the success of the project: description and understanding of the existing river system; direction regarding future research needs and monitoring of river ecology; and the capacity to estimate changes in the river by inference rather than supposition.

To understand the Gambia River in an ecological and economic context, it was necessary to identify and study factors which affect the distribution and abundance or organisms in the river. By observing the response of the ecological community to these factors, inferences could be made regarding the influence of basin development on the river.

The sampling program adopted for fish and other components of the river resource study included as many factors as possible given our finite resources. To achieve an integrated analysis of factors affecting the river system, a series of study components was postulated along with their

relationships among one another (Fig. 3). This conceptual model emphasized both points of factor effects in the ecological system and the exchange of materials (energy) within the system. For example, autochthonous and allochthonous inputs of nutrients such as nitrates and phosphates were recognized as important components of the nutrient exchange cycle and were included as analytical factors in studies on water and nutrient chemistry. Densities of phytoplankton, zooplankton, and larval fish were hypothesized to influence the relative abundance and distribution of adult fish and were also included as analytical factors in the study.

To direct intensive field sampling and analysis of data a stratified sampling scheme was used. Our premise was that a thorough understanding of environments and processes represented at a few select locations along the river that were representative of the river system as a whole was preferable to a superficial understanding at a multitude of locations. Results of these intensive studies were extended to the river system as a whole. Supplementary study locations and sampling efforts were included when data were needed to more fully understand changes or transitions in river system ecology. The net result of these analytical precepts was a sampling plan which attempted to maximize the information obtained from each sample while limiting total number of samples collected to achieve research objectives.

SAMPLING AND ANALYTICAL DESIGN

River Survey

A primary consideration in the experimental design of this study was the concept that the Gambia River has distinct ecological zones. This concept originated from review of previous studies on this river (Svensson 1933,

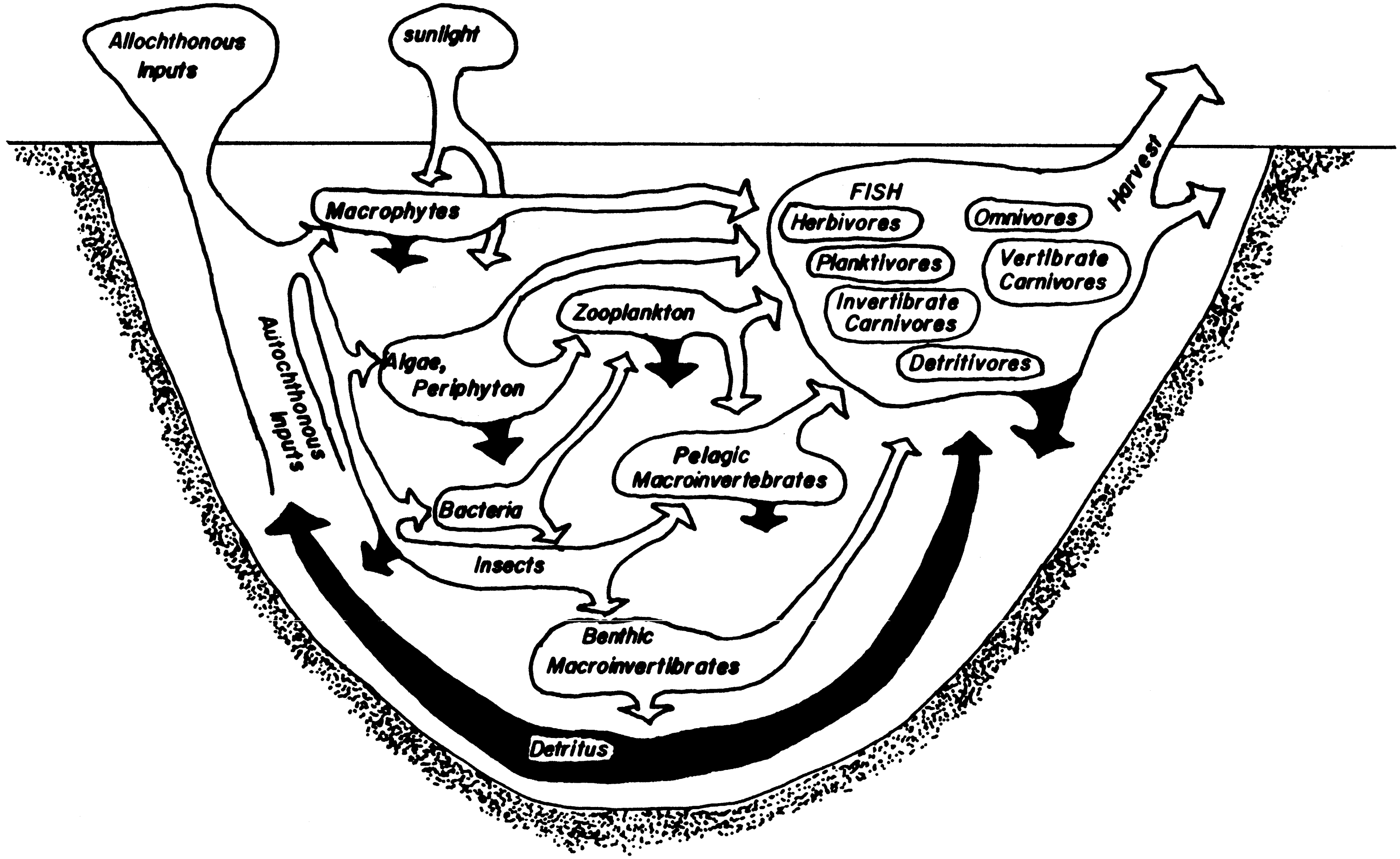


FIG. 3. Hypothesized relationships between some physical, chemical, and biological components of the Gambia River, West Africa.

Johnels 1954, Monteillet and Plaziat 1979) and others (Welcomme 1979, Beadle 1981) and reconnaissance of the Gambia River in February 1983. Five major ecological zones were identified and sampling was concentrated at one or two locations in each zone. These zones were the lower estuary, upper estuary, lower river, upper river, and headwaters; each zone was characterized by a suite of physical, chemical, and biological characteristics which delineated approximate geographic boundaries between zones.

The working definition of each zone was as follows: lower estuary - salinity >30 ppt throughout the year with a distinctly marine flora and fauna; upper estuary - salinity ranging from measurable levels to 30 ppt and presence of mangroves; lower river - fresh water throughout the year, presence of tidal fluctuations, and slow moving without rapids; upper river - fresh water throughout the year, absence of tidal fluctuations, and presence of occasional rapids; headwaters - fresh water with abundance of tributaries, rapids and pools, and flowing through hilly or mountainous terrain. Geographically, the upstream boundaries of these zones were approximated as follows: lower estuary - Mootah Point, The Gambia; upper estuary - Kuntaur, The Gambia; lower river - Goloumbou, Senegal; upper river - the major escarpment immediately south of the Senegal/Guinea border; headwaters - the river source near Labé, Guinea (Fig. 4).

In keeping with our approach of intensive field sampling at a limited number of representative locations within each zone, five major sampling sites were selected, one within each zone. Distribution of these sites was as follows: lower estuary - the Dog Island area in The Gambia; upper estuary - 3 km east of Bai Tenda, The Gambia; lower river - 4 km west of Bansang, The Gambia; upper river - Kedougou, Senegal; headwaters - the bridge crossing

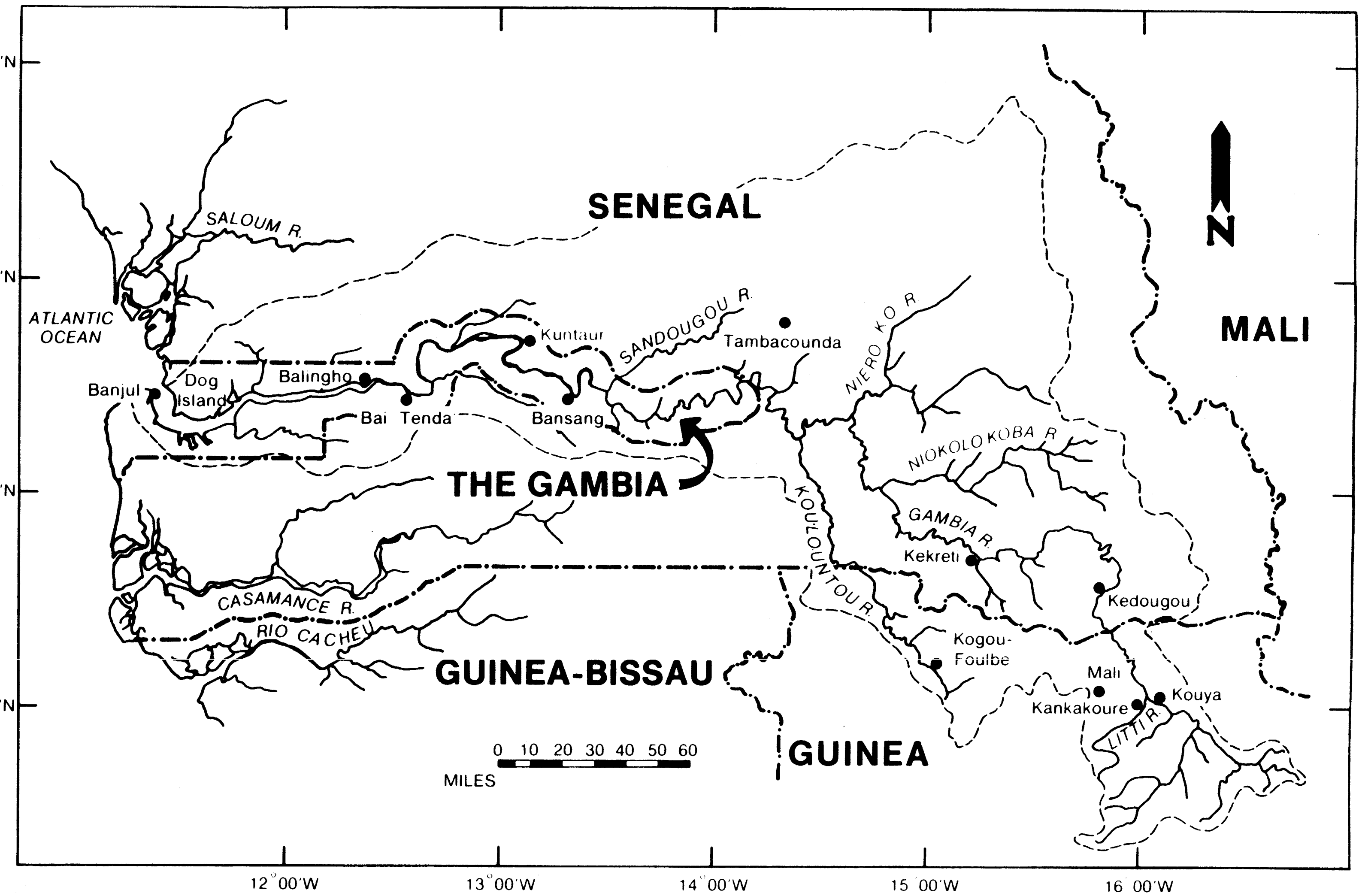


FIG. 4. Drainage basin of the Gambia River, within dashed lines.

of the Gambia River 20 km south of Balaki, near Kouya, Guinea (Fig. 4). An important supplementary sampling location was located at the proposed site of the Kekreti dam in Parc Nationale de Niokolo Koba, Senegal.

Each of these five ecological zones was comprised of four major habitats. These regions were, laterally, the nearshore region and the offshore region and, vertically, the pelagic region and the benthic region. If the longitudinal dimension of the river is included in a three-dimensional description of the river, four major habitats may be defined: nearshore pelagic, offshore pelagic, nearshore benthic, and offshore benthic. Additional habitats peripheral to the main river channel include tributary rivers and streams, dendritic lateral extensions of the river in its lower or floodplain reaches (these extensions are locally referred to as "bolons"), intertidal regions which often support growth of mangroves, and floodplain areas which are inundated for varying periods of time and may contain mud or grass flats along with portions that are covered by brush or trees.

Major sources of variation expected to influence the abundance, distribution, biology, or ecology of fish were grouped into two sets: spatial variation and temporal variation. Three sources of spatial heterogeneity were identified within the river itself: variation with longitude (i.e., along the river); variation with latitude (across the river); and variation within the vertical plane (through the water column). Two sources of temporal variation were identified in the lower estuary, upper estuary, and lower river zones: diel (day-night) and tidal (flood-ebb) periodicity. In the upper river and headwaters zones, only diel periodicity was present.

To include effects of spatial variation in our analytical design, samples were collected in each of the five ecological zones, at four transects along

the river to assess longitudinal variation within zones, at four stations along each transect to assess lateral variation across the river, and at four depths at each station to assess vertical variation in the water column. Distance between transects was equal to the width of the river at the sampling site and varied from 100 m in the upper river zone to more than 1,000 m in the lower estuary zone. Distances between stations and between depths were proportioned equally according to the width and depth of the river at the sampling sites. These distances, therefore, were not fixed but expanded or contracted in accordance with the size of the river - this allocation of sampling effort with fixed numbers of sites and flexible distances between sites follows a "balloon" concept sample site allocation.

Temporal variation was considered by collecting samples at different times of the year, the 24-hour day, and phases of the tide cycle. Sampling was conducted four times during a one-year period (June-August 1983, September-October 1983, November-December 1983, and February-March 1984) to assess seasonal changes in climate, river hydrology and chemistry, and biological activity. In the lower estuary, upper estuary, and lower river zones, diel and tidal variation was considered as a split factor (diel-tide period - day flood, night flood, day ebb, night ebb). In the upper river zone where tidal effects were absent, diel variation alone was considered. Our initial sampling efforts divided the diel period into four levels - dawn, day, dusk, and night. However, our first sampling of the river (June 1983) dictated that the crepuscular periods, dawn and dusk, were too brief to sample effectively with our design and gear. Therefore, diel-period sampling was reduced to day and night.

A model commonly used for this type of ecological investigation would be a four-level complete-block design (Winer 1971). With such a model, the sampling program might consist of five zones with four transects within each zone, four stations per transect, and four depths at each station. This design should be repeated four times in each zone to cover the four combinations of the diel-tide split factor or diel factor. Sampling must then be repeated four times throughout the year to cover the four stages of the river: rising water, peak flood, declining water, and low water. This yields a total of 5 x 4 x 4 x 4 x 4 x 4 or 5,120 samples not including possible replication - a sampling effort far beyond our capacity. However, by making some statistical assumptions, a more efficient sampling program was achieved with a Greco-Latin Square model. This model provided a considerable reduction in numbers of samples collected, while allowing for testing of all relevant research hypotheses concerning spatial heterogeneity and temporal variation in abundance and distribution of fish. These hypotheses can be considered as the following series of questions: were there statistically significant differences among zones, among transects within a zone, among stations within a zone, among different depths, between day and night, between flood and ebb tide, and among seasons? The major statistical assumption required for use of this Greco-Latin Square model is that there was no interaction among any of the main-effect blocking variables or factors (Winer 1971, Netter and Wasserman 1974). Statistical tests were conducted to evaluate the extent to which this assumption was violated and would subsequently affect the strength of our conclusions. By using this four-sided Greco-Latin Square model, only 16 samples were required in each zone during the four sampling periods.
This yielded a overall design with 5 zones x 16 samples/zone x 4 river flood

stages which equals 320 samples, a reduction of 93.75% from the complete blocks design. This reduced sampling scheme also permitted collection of replicate samples and the incorporation of other sub-programs in the river survey, while retaining the capacity to test previously stated research hypotheses.

Using the previously described four levels of each of the spatial (zonal, longitudinal, lateral, vertical) factors, the four habitats previously identified in the main channel, i.e., nearshore pelagic, nearshore benthic, offshore pelagic, and offshore benthic, were defined in three-dimensional matrix (i, j, k) notation as sets of cells within the matrix (Fig. 5, Table 1). Temporal factors, e.g., diel-tide or diel period, were considered as a fourth dimension to this habitat matrix during sampling and analysis of data. Although the intertidal bolon-mangrove complex and floodplain habitats are not detailed in the above matrix (Fig. 5), modified Latin Square models were superimposed on these habitats in a manner similar to the main river channel.

The guiding principle of sample collection was that the Greco-Latin Square model defined the particular time, depth, and location of a sample. Then, selected collecting techniques were employed to obtain a representative sample from the designed location. For example, in accordance with this design, during the second sampling period a surface sample was collected during a daytime flooding tide at station one on transect one. This transect-one station-one sample was repeated in each of the lower three zones.

The intent of using the Greco-Latin Square model with the fish sampling program was to overlay a statistical framework of sampling and analysis on the investigation of abundance, distribution, and biological activities of fish.

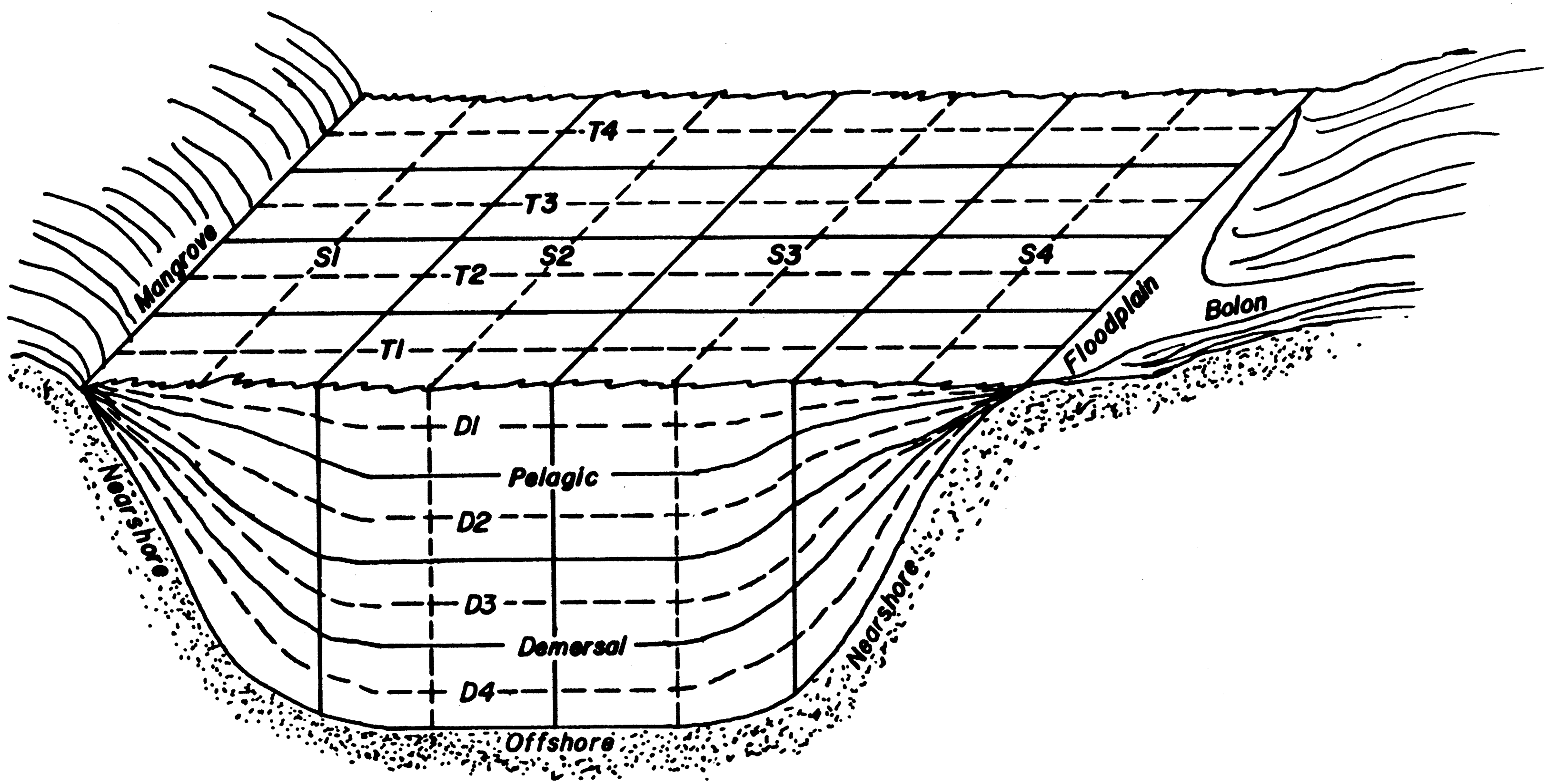


FIG. 5. Scheme of Gambia River habitat with superimposed 4 x 4 x 4 matrix of cells. Cell boundaries are indicated by light solid lines. Transect (T1-T4), station (S1-S4), and depth (D1-D4) vectors are shown as dotted lines along cell mid-points. Habitat zones (nearshore pelagic, offshore pelagic, nearshore demersal, offshore demersal) are composed of cells as indicated.

TABLE 1. Major habitats identified within the main channel of the Gambia River. Portions of the river comprising each habitat are represented by sets of cells. Cell mid-points are denoted in three-dimensional matrix (i,j,k) notation where i = transect loci, j = station loci, and k = depth loci.

Habitat	Cell mid-points
Nearshore benthic	(1,1,3), (2,1,3), (3,1,3), (4,1,3), (1,1,4), (2,1,4), (3,1,4), (4,1,4), (1,4,3), (2,4,3), (3,4,3), (4,4,3), (1,4,4), (2,4,4), (3,4,4), (4,4,4),
Offshore benthic	(1,2,3), (2,2,3), (3,2,3), (4,2,3), (1,2,4), (2,2,4), (3,2,4), (4,2,4), (1,3,3), (2,3,3), (3,3,3), (4,3,3), (1,3,4), (2,3,4), (3,3,4), (4,3,4),
Nearshore pelagic	(1,1,1), (2,1,1), (3,1,1), (4,1,1), (1,1,2), (2,1,2), (3,1,2), (4,1,2), (1,4,1), (2,4,1), (3,4,1), (4,4,1), (1,4,2), (2,4,2), (3,4,2), (4,4,2),
Offshore pelagic	(1,2,1), (2,2,1), (3,2,1), (4,2,1), (1,2,2), (2,2,2), (3,2,2), (4,2,2), (1,3,1), (2,3,1), (3,3,1), (4,3,1), (1,3,2), (2,3,2), (3,3,2), (4,3,2)

Also, the extent to which the dynamics of fish life history could be attributed to selected abiotic and biotic factors and cyclic phenomena within the various ecological zones and habitats was evaluated. Finally, the model dictated the most efficient allocation of sampling effort.

The concepts and design of our study program in all zones but that of the headwaters have been described. Three modifications occurred to this program and involved the lower estuary zone, the upper river zone, and the headwaters zone.

During first-period sampling in the lower estuary zone (August 1983), sampling followed that prescribed by the Greco-Latin Square design. However,

there was a change in fishing technique from trawling to gillnetting following this sampling period.

In the upper river zone, the Greco-Latin Square model guided investigation of three of the four spatial factors: ecological zone, transect, and station. Because the river was shallow (<2 m) and our gear (seines and gill nets) sampled the entire water column, depth was omitted as a factor in our analysis of variation and spatial effects. Because tidal effects were absent, temporal effects were limited to those of season and diel period. Four seasonal samplings of this zone were conducted as previously described. But the brevity of the crepuscular period prohibited effective sampling with gill nets, which were our primary sampling gear. Therefore the diel factor was reduced to two levels - day and night.

Our studies in the headwaters zone began during the third sampling period (November-December 1983) as a result of an addition to our research contract. Sampling in this zone was extended to include a fifth period (June 1984). Our experimental approach and design in the headwaters zone differed from that established for the other zones. Emphasis was placed on collection of baseline data and preliminary system analysis; detailed analysis of trophic relationships, cause-and-effect processes, and spatial or temporal variation was not attempted.

Two major regions were identified to exist within the lateral extent of the river at the sampling site: nearshore (within 2 m of the river bank) and offshore (beyond 2 m of the river bank). Within each of these regions the following habitats were postulated and sampled when present: nearshore - shallow riffle (depth <1 m, current >0.6 m/sec.), deep riffle (depth >1 m, current >0.6 m/sec), shallow slow-run (depth <1 m, current 0.1-0.6 m/sec),

deep slow-run (depth >1 m, current 0.1-0.6 m/sec), shallow pool (depth <1 m, current measurable-0.1 m/sec), deep pool (depth >1 m, current measurable-0.1 m/sec), shallow backwater (depth <1 m, no measurable current), deep backwater (depth >1 m, no measurable current); offshore - same eight habitats as described for the nearshore region. Currents were established by measuring river flow in the various habitats with a current meter. Night sampling was conducted only with passive gear that could be set during the daylight period to avoid hazardous conditions after dark such as unanticipated currents, deepwater areas, and snakes.

Special Studies

The estuarine section of the Gambia River is a complex environment which consists of a main river channel, and numerous habitats peripheral to the main channel which include: shallow intertidal mud banks at the edge of the river, bolons, mangrove swamps, and seasonal floodplains. Mangroves are found only in tidal areas with salinities always greater than 1 ppt. The structure and function of the river ecosystem are closely tied to the presence of these habitats peripheral to the main river channel. Tidal flushing induces a large exchange of water between the main river channel and these peripheral areas as does seasonal inundation of the floodplains. As a result, processes which occur within these various habitats ultimately affect the water of the Gambia River and its flora and fauna.

Most of our effort was directed toward study of the main river channel. Our assumption was that the influence or role of the peripheral habitats in the river system would eventually be reflected in the ecology of the main river channel. However, to obtain some understanding of physical, chemical,

and biological processes in these peripheral habitats we conducted special studies in two of them; a bolon and a floodplain.

The objective of both special studies was to compare and evaluate abundance, distribution, feeding, and maturation of fish in these habitats with those observed in the main channel. This knowledge would improve our understanding of the individual contribution of these various habitats to total river system ecology. An additional objective for both special studies was to obtain estimates of standing stock which might be valuable when inferring distribution of fish production within the river system.

To minimize spatial effects and variance, the bolon and floodplain study sites were adjacent to the lower estuary sampling site in the main river channel near Bai Tenda, The Gambia. Sampling was conducted concurrently at all three sites to minimize temporal variance.

The bolon that we sampled was fringed by mangroves and intertidal mud banks and had floodplains adjacent to it. Spatial differences in abundance and distribution of fish were studied by simultaneous sampling in the main river channel, at the mouth of the bolon, and at the upstream end of the bolon. Temporal differences were studied by seasonal (flood and low water periods) and diel-tidal cycle sampling as described previously for the main river channel. Estimates of standing crop were obtained by poisoning a measured section of the bolon and retrieving dead fish along with making estimates of percent total kill that was not collected.

The floodplain study was conducted in a small area adjacent to the bolon. The floodplain was composed of flat open areas of mud or grass and was surrounded by mangroves. The entire floodplain was flooded at high tide and was completely exposed at low tide. Entry and exit of water was confined to a

small (50 m) section of the bolon channel bank. The hydrology of this floodplain was judged to be typical (and representative) of most floodplain areas that we examined during study site selection. This particular floodplain was chosen for study because it presented a small well-defined area that could be adequately sampled and presented minimal spatial variance. Spatial effects on this flood plain were presumed relatively unimportant in comparison with diel and tide effects. Therefore, sampling followed the split factor analysis of diel-tidal effects and was conducted simultaneously with sampling in the bolon and main river channel. Estimates of standing crop were obtained by poisoning fish after they moved onto the floodplain with the incoming tide.

As described, an attempt was made to investigate spatial and temporal effects on the abundance and distribution of fish in the bolon and on the floodplain as was done in the main river channel. Sampling was conducted concurrently among these various habitats to minimize temporal variance. However, the Greco-Latin Square model and sampling design was not imposed upon our bolon and floodplain studies because our primary interest and intent was to investigate relative differences among habitats rather than spatial variance within the bolon or floodplain.

DATA PROCESSING

Data Bases

Data were compiled from four general sources: literature, on-going studies within the basin outside of our project, data compiled by other teams within our project, and data compiled during our studies on the river.
In general, data obtained from the first two sources were used to expand our understanding of our data and the river system. Data compiled by other teams

were drawn upon to provide a more integrated and detailed understanding of river system processes.

Our data were separated into two general categories: main river channel survey data and special studies data. Within the river channel survey category two data bases were established: standard series data and non-standard-series (or supplementary) data. Standard series data were those data compiled during sampling with fixed effort and gear according to the Greco-Latin Square design or the modifications to it in the upper river and headwaters zone. The standard series data base was used extensively for hypothesis testing, analysis and explanation of variance, detection of cause-and-effect relationships, and comparisons of fish abundance, distribution, and biological activities among habitats and ecological zones. Non-standard-series data were data compiled during sampling without a sampling design but rather as opportunity permitted. The supplementary data base was utilized to complement and expand our understanding of results of standard series data analysis and of the river system.

Within the special studies data category, two general sub-categories were established: bolon study data and floodplain study data. Within each of these sub-categories data on abundance, distribution, and biological processes were separated from data on standing stock.

All of the described data provided the basis for our interpretations and inferences regarding the biology and ecology of fish and other aspects of the aquatic system. Also, our integrated analysis of the Gambia River system was based upon evaluation of these data and the results of our analyses.

The variety of habitats combined with the range of fish sizes and life stages necessitated sampling with a spectrum of gear (Table 2, Appendix 1);

TABLE 2. Summary of gear, targeted habitat and fish lifestage, and associated index of abundance resultant from studies on the Gambia River, 1983-1984.

Gear	Habitat[1]	Lifestage[2]	Index of Abundance
		Passage Gear	
Gill net	IP, ID, OP, OD	A, J	CPE[3]
Trap net	IP, ID	A, J	CPE
Blocking net	IP, ID	A, J	Density[4]
Trot line	IP, OD	A	CPE
		Active Gear	
Seine	IP, ID	A, J, L	CPE
Trawl	OP, OD	A, J	CPE
Cast net	IP, ID	A, J	CPE
Electrofisher	IP, ID	A, J	CPE
Echosounder	IP, OP	A	CPE
Plankton net	IP, OP	L	Density[5]

1 IP = nearshore pelagic; ID = nearshore demersal
OP = offshore pelagic; OD = offshore demersal
2 A = adult; J = juvenile; L = larval
3 CPE = catch-per-unit-effort
4 Density = no./hectare
5 Density = no./1,000 m^3

details of sampling are discussed later (see Sampling Methods). Sampling with different gear should be considered a separate and distinct experiment since each gear is subject to different biases. However, the bias of each gear was assumed to remain constant over time and sampling areas. Units of effort were also standardized, e.g., 10-minute haul with a 4.9-m semi-balloon trawl. The combination of constant bias and standard units of effort provided assurance that catch-per-unit-effort (CPE) was a reliable index of abundance for any fish species in the study area (Ricker 1975). We elected to analyze the abundance and distribution of adult and juvenile fish populations by use of CPE indices which comprised the standard series data base. An exception was standing stock estimates based upon fish densities (no./hectare) or

biomass (kg/hectare) derived from sampling with blocking nets and poison. Also, abundance of larval fish was expressed at densities (no./1,000 m^3) via calibrated flowmeters attached to plankton nets.

Data Entry and Processing

Data on physical and limnological conditions associated with field sampling collections, as well as data resulting from laboratory analysis of samples, were recorded on field or laboratory log sheets in a prescribed format. These data were then entered on 80-column coding forms and later entered onto computer disk files for storage, manipulation, and analysis.

We included stratifying variables to facilitate computer sorting and analysis of data as well as to investigate sources of spatial and temporal effects. These stratifying variables were: ecological zone (5 levels), longitudinal zone - transect (4 levels), lateral zone - station (4 levels), vertical zone - depth stratum (4 levels), sampling period - time of year, which corresponded with the hydrological cycle (4 levels), and diel tidal cycle (4 levels) or diel period (4 levels). As noted previously, some pooling of vertical and cyclic variables was performed during sampling and/or analysis of data from the upper-river and headwaters zones.

Individual fish records contained the following information: data base category, date of collection, time of collection, fishing duration, gear type, replicate, transect, station, depth, diel-tide or diel period, bottom depth, fish species identification code, unique fish number, length, weight, sex, gonad condition, presence or absence of food, subsample information (described below), and stomach content identification code.

The microcomputer software package dBase-II was used to facilitate data management procedures which included data sorting, calculating statistics, generating tables, and writing data into formats that were subsequently processed by other programs. We used dBase-II to format all data, to generate summary data on maturational condition of gonads, diet, and distribution of sex ratios, and for preparing input data for use by other programs.

Calculations performed on the bulk of the standard series data were handled by a FORTRAN program developed specifically for the task. Data on adult and larval fish caught during standard series fishing were divided into 10-mm length groups identified by their midpoints, e.g., fish in the 105 to 114-mm range were assigned the 110-mm interval. Before numbers of fish were added to a length group a correction factor for gill net set time was used. All nets were standardized to a six-hour fishing period which corresponded with the duration of each phase of the tidal/diel cycle; fish catch was adjusted accordingly. Justification for this adjustment was based on our assumption that catch and time have a linear relationship, and the need to base catch comparisons in equivalent units of fishing effort. Length-frequency data were written onto disc files which were then manipulated with a graphics program (written in BASIC) to produce the actual plots.

The program also calculated total numbers based on a subsample of the catch as follows: during laboratory workup, fish were sorted into groups representing 1-2 length intervals (i.e., range of 20 mm). These fish were weighed as a single weight, and a sample was taken from each mass weight group. The fish in the sample were then analyzed according to standard procedures and their length-weight data were assumed to be representative of the total mass weight. Mean weight of the subsampled fish was then calculated

and divided into the mass weight to determine the number of fish not examined. This number was then subdivided and allocated among the length intervals represented by the subsampled fish in proportion to the number of subsampled fish in each length interval.

Analytical Procedures

Several approaches were taken to best analyze and interpret the data. Initially, for all data collected in each of the 5 zones (standard series and supplementary catches), histograms and summary tables were used to look for general trends in abundance, distribution, feeding, and gonad maturational patterns.

Parametric statistical procedures such as comparisons and analysis of variance were primarily limited to standard series data collected in the lower and upper estuary and lower river zones due to unavoidable incompatibilities in supplementary data collection procedures. Parametric statistics available within the framework of the program included length-weight regression, Latin Square analysis, and two-way analysis of variance. Length-weight regressions for all species were carried out on log10 transformed data and expressed in the form of back-transformed equations; only individual fish records were included in this analysis (mass weight data excluded).

Analysis of data compiled during sampling in accordance with the Latin Square design described earlier was performed on adjusted catch. Thirty-two standard series nets (16 nets at 2 replicates each) were set in the lower river, upper estuary, and lower estuary zones during a sampling period and mean catch in each of the 4 levels within the transect, STATION, DEPTH, and TIDE factors were compared. In addition to the F-tests for these four

factors, the output included lack of fit and pure error terms to aid in the interpretation of results. For the two-way analysis of variance performed for each zone and flow regime for the lower river and the upper and lower estuary zones, catches were pooled in the following manner: stations 1 and 4 were combined as nearshore catch, and 2 and 3 were combined as offshore catch. The two upper depths were combined to represent pelagic catch and the two lower nets combined as benthic catch. This 2 x 2 balanced, factorial design was structured to detect differences in catch among habitats. To aid in the interpretation of results from these analytical procedures a series of tables which summarized catch pooled by tide was also generated.

SAMPLING METHODS

For standard series sampling, collection with one gear was required to ensure equity of comparisons among CPEs. The combination of current, steep river banks and nearshore deepwater, and presence of dense fringing vegetation resulted in the selection of gill nets as the most effective sampling gear given the spectrum of river conditions encountered during the study.

However, our intent was to sample as many species and sizes of fish in as many habitats as possible; selective or target fishing was avoided. But because fishing with any single gear is somewhat selective we used other gear in addition to gill nets to supplement our database and increase our understanding of fish abundance and distribution. These supplemental gear included: trawls, seines, trap nets, cast nets, long lines, block nets, electrofishers, poison (rotenone), and echolocation for adult and juvenile fish and plankton nets for juvenile and larval fish. Appendix 1 summarizes the

technical specifications of all gear used during the study; the selectivity and type of data associated with these gear were discussed earlier (Table 2).

Adult and Juvenile Fish

Nylon experimental gill nets 36.6 m x 1.8 m were set within appropriate cells of the sampling grid during diel-tide periods established by the Greco-Latin Square experimental design. Each gill net was composed of 12 panels, each 3-m long, starting with 1.3-cm bar mesh and proceeding in 0.6-cm increments up to 7.6-cm mesh, with the last panel having 10.3-cm mesh. Two such nets fastened end-to-end were set together and treated as replicates. Standard sampling with gill nets consisted of sets that were oriented parallel with the current. Supplemental gill nets were occasionally fished oriented perpendicular to the current. These sets trapped much more leaves and debris than the sets parallel to the current. But fish catches did not appear to differ in either quantity or species distribution. Therefore, sets parallel to the current were established as standard operating procedure.

Gill nets used during this project were originally designed to fish on bottom. But modifications were made to the nets to enable them to fish throughout the water column. Surface sets were accomplished by attaching numerous floats to the upper line, thus suspending the net from the surface. Mid-water sets were accomplished by attaching floats at widely spaced intervals along the surface and allowing the net to drape down into the water column.

A semi-balloon, nylon otter trawl having a 4.9-m headrope and a 5.8-m footrope was used for supplementary fishing. The body and cod end of the net were composed of 1.9-cm and 1.6-cm mesh, respectively, while the cod end

interliner was 0.6-cm mesh. Trawls were made parallel to shore with the R/V Laurentian. Trawling was performed in the lower estuary, upper estuary, and lower river. All trawl hauls were made at an average speed of 4.8 km/hour. Hauls were taken both with and against the current and on bottom (benthic trawls) or off-bottom in the water column (pelagic trawl).

Seining was performed with a 1.8-m x 3.7-m seine having 0.3-cm mesh. The seine was hauled at various locations in the river depending upon depth and accessibility.

Special studies sampling the bolon and floodplain necessitated modifications to our river survey sampling methods previously described. Sampling was conducted with gill nets in combination with rotenone and blocking nets. Gill nets were set in main river channel and at locations just inside and well upstream of the bolon mouth. Comparisons were made among CPEs at these locations to analyze fish abundance and distribution. A 1,000-m-long portion of the bolon was blocked off and rotenone was applied at high slack-water. As fish surfaced, they were dipnetted or swept down the bolon with the ebbing tide and trapped in the lower blocking net. An attempt was made to estimate percent of fish not collected relative to total number observed. The bolon was sampled twice - once during peak river flood (October 1983) and once during low water (March 1984) to evaluate abundance and distribution of fish during the extremes of the hydrological flow and salinity regimes. Sampling was limited to a single diurnal tide cycle since fish could not be seen for collection at night.

The area and depth of a small floodplain adjacent to the bolon was measured during peak high tide to obtain numerical estimates as described for the bolon study. The single point of exit for water collected on the flood-

plain was blocked with a net at high slack-water and the impounded water was treated with rotenone. The floodplain was drained completely at low water and all fish were either trapped in the blocking net or stranded on the floodplain where they were gathered by hand. One diurnal and one nocturnal tide cycle were sampled during the period of peak river flood (October 1983) - the floodplain was not inundated sufficiently to justify sampling during low water (March 1984).

Fish samples were labeled and separated in plastic bags. Fish were processed while fresh when time permitted, frozen on board the R/V Laurentian in the lower three zones, or preserved in a solution of 10-20% formaldehyde in the upper two zones where freezers were unavailable. For field and laboratory examination, fish in each bag were separated by species, then grouped into similar size classes. When many specimens were contained in a single size class, a subsample was randomly taken from the group and the remaining fish weighed (herein referred to as the mass weight) and discarded. The following data were recorded for each fish except those in mass weights: total length (to the nearest mm, caudal fin pinched); weight (to the nearest 1 g or 20 g depending on whether the fish was less than or greater than 1,000 g, respectively); sex; maturational state of gonads; presence or absence of food in stomach; and evidence of diseases or macro-ectoparasites. Stomach contents were identified or preserved in formaldehyde for later identification.

Maturational state of gonads of adult fish was described according to five stages of development: (1) slightly developed; (2) moderately developed - for female, eggs discernible but not ripe; (3) ripe; (4) ripe-running - sex products exuded with moderate pressure and; (5) spent. Other gonad conditions recorded included: (6) immature; (7) unable to ascertain sex of adult fish;

(8) reabsorbed eggs and; (9) fish decomposed or mutilated so that sex or maturational state was impossible to determine.

All fish were identified to species using Rainboth (1983), with the exception of a few specimens of the genus *Dasyatis*. These rays were most likely *Dasyatis margarita*, but positive identification was not possible because of confounding characteristics.

For each adult and juvenile fish examined, the following information was recorded on an 80-column coding form, one line per fish: data type (river survey - standard series, supplemental; special studies - bolon, floodplain); data block number; date, time, and duration of gear deployment; gear type; replicate identifier; ecological zone; diel-tide cycle; transect; station; depth stratum fished; total depth of water at station; use of fish (whether whole fish, stomach, or scales were saved for later examination); subsample information (when applicable); and classification of food items when recognizable.

Data on subsampled fish were recorded on consecutive lines, each having a subsampling code. Special columns were reserved for the corresponding mass weight. Computer programs searched for subsampled lots and calculated number of mass-weighed fish not examined. Mass-weight fish were proportionally assigned to length intervals. Fish were divided visually by length into many size classes when originally subsampled to minimize error associated with this reconstruction of sample length-frequencies.

Larval Fish

A conical, 0.5-m diameter plankton net of no. 2 mesh (363-micron aperture) was used to collect larval fish, arbitrarily defined as any fish

less than 25.4 mm total length (TL). A Model 2030 General Oceanics digital flowmeter was attached to the center of the net to measure the volume of water sampled. The flowmeter was calibrated by towing a ring (without a net) equipped with a flowmeter suspended in the center by wires, for a known distance in the river. One count of the flowmeter was found to be equivalent to 5.2 liters of water filtered by the 0.5 m net.

In deep water (>2 m), the plankton net was towed from a 6-m outboard motor boat for 3 minutes at an average speed of 2-3 km/h. Tows were generally made against the current and an 8 kg hydrodynamic depressor was used for all boat tows to sink and stabilize the net underwater. For each tow, approximately 20-30 m^3 of water was filtered, depending on current speed and clogging of the net by algae and other suspended particles. In shallow water, the net was towed just under the water surface by hand.

Replicate samples were taken at each station during each tide cycle as follows: first, the plankton net with attached depressor was lowered to the bottom from a stationary boat. An oblique tow was performed by slowly raising the net toward the surface while the boat was moving, thus filtering water from the entire water column. Next, the plankton net was washed down and the sample was collected in a wide-mouth glass (0.4 liter) Mason jar. Finally, the sample was preserved in 10% formaldehyde, labeled and sealed, and the flowmeter reading recorded.

Fish eggs and larvae were removed from samples with the aid of a binocular dissecting microscope. Once the larvae were extracted from the samples, they were measured to the nearest 0.1 mm TL except when samples contained more than 20 larvae of any species, at which point lengths were measured to the nearest 0.5 mm. When large numbers of eggs were present in a

sample, only 20 eggs were removed and saved. All fish eggs in the sample were tabulated on a hand counter. Samples containing large numbers (>200) of larvae were subsampled using a Folsom plankton splitter which divided the sample in half. Splitting was done from one to several times in order to reduce to about 100 the number of larvae in the subsample. To ensure that all larvae in a sample were picked, the sample was examined twice.

Number, species or taxa, and lengths of fish larvae as well as number of eggs found were recorded on an 80-column coding form and later entered into computer files. A computer program was developed to calculate the density (no./1,000 m^3) of eggs and larvae in a sample using the flowmeter readings. For density calculations, we assumed that the number of larvae caught while the net was lowered to bottom was zero, since the net was stationary and draped shut. We also assumed that densities calculated for oblique tows represented an average for the water column.

Fish larvae collected were identified to family or genus using taxonomic information from Lippson and Moran (1974), a CICAR Ichthyoplankton Workshop report (UNESCO 1975), and Johnels (1954). Information on spawning seasons of fish species in a given river zone and data on maturational condition of gonads of adult fish collected in conjunction with larval fish also aided in identification of larvae. Because a taxonomic key to identification of fish eggs commonly found in the study area did not exist, no attempt was made to identify fish eggs collected. Young-of-the-year fish longer than 25.4 mm that were caught in plankton nets were designated as fry. Data on fry were entered on the same coding forms as fish larvae, but fry densities were calculated separately from larval fish densities.

DEFINITION OF TERMS

For purposes of this report the following standardized terminology and definitions were made:

Ecological zone - The river system was hypothesized to be composed of five regions, each of which had a set of distinguishing physical, chemical, and biological characteristics. These zones were: headwaters, upper river, lower river, upper estuary, and lower estuary.

Habitat - The main river channel was that portion of the river which did not extend beyond the river banks. It was subdivided laterally into a nearshore (the quarter of the river width adjacent to the river bank) and offshore (the quarter of the river width adjacent to the river midline) components. Therefore, each component comprised 50% of the total width of the river. Similarly, the main channel was also subdivided into an upper or pelagic region and a lower or benthic region; each comprised one half of the water column. In reality the zone of influence associated with the nearshore and benthic components was probably considerably smaller than the offshore and pelagic components. But for this study, this probable disparity was ignored and the main channel was then divided into four regions: nearshore pelagic, nearshore benthic, offshore pelagic, and offshore benthic. Habitats peripheral to the main channel included the intertidal region (alternately exposed and inundated with the tide cycle), the bolon/mangrove region or complex (feeder streams fringed and overhung by mangroves), and the floodplain (open expanses of mud or grass-covered flats - either intertidal or covered by shallow water <1 m deep).

Hydrological stage - When referring to the height of the river or extent of flooding, we spoke of rising water, peak flood, declining water, and low water stages. When speaking of flow (velocity) we used the terms increasing, maximum, decreasing, and minimum flow. The terms lotic (running water habitat), lentic (standing water habitat), riffle, slow-run, pool, and backwater were used in their standard limnological contexts to describe aquatic conditions or regimes.

Spatial variance - Variation or differences in abundance and distribution of fish that were a function of the physical separation between sampling locations and changes in ecological parameters between those points. Three sources of spatial variation were hypothesized: longitudinal (reflected among zones and transects), lateral (reflected among stations), and vertical (reflected among depths).

Temporal variance - Variations or differences in abundance and distribution that were a function of changes in ecological conditions at a location as a function of time. This variation was cyclic and included seasonal (reflected as differences among sampling periods), daily (reflected in 24-hour sampling), and tidally (reflected in tide-cyle sampling) induced changes or differences.

Diel period - This refers to the 24-hour day. Diurnal - activity by daylight; nocturnal - activity by night; crepuscular - activity by dawn and dusk only.

Split factor - Where two sources of variation or factors inducing variability were measured in combination with each other. In the tidal region of the river, diel (day, night) and tidal (flood, ebb) regimes were measured in combination as: day-flood, day-ebb, night-flood, and night-ebb.

Marine - Habitat or conditions where salinity was greater than 30 ppt.

Estuarine - Habitat or conditions were salinity was measurable but less than 30 ppt.

Freshwater - Habitat or conditions of no measurable salinity.

Adult fish - Sexually mature.

Juvenile fish - External features and characteristics similar to those of adult but sexually immature.

YOY - young-of-the-year - Fish in their first year of life; they become yearlings 1 January.

Fry - Any fish equal to or greater than 25.5 mm in total length (defined below).

Fish larvae - Any fish less than 25.5 mm in total length.

Total length (TL) - Length of fish from most anteriorly projecting part of head to farthest tip of caudal fin when caudal rays are squeezed together.

Adult fish length intervals - For figures describing total lengths of adult fish, individuals were assigned to 10-mm intervals. For example, the 30-mm length interval would include fish from 25 to 34 mm.
For length-frequency histogram figures, size ranges for adult and juvenile fish were determined from length modes of fish collected during each sampling period. Size ranges of each of these groups may be slightly different for different sampling periods.

Larval fish length intervals - For figures describing total lengths of larval fish, a specimen was assigned to a 0.5-mm interval based on total length. For example, 0.3 mm larvae would be assigned to the interval 0.5 mm (which includes all larvae 0.1 to 0.5 mm), 5.6-mm larvae would be assigned to the interval 6 mm (which encompasses 5.6- to 6.0-mm larvae).

Anadromous - Fish that live in salt water and migrate to fresh water to spawn (e.g., some salmon).

Catadromous - Fish that live in fresh water and migrate to salt water to spawn (e.g., some eels).

Diadromous - Fish that migrate between fresh water and salt water (includes anadromous and catadromous fish).

Euryhaline - Tolerant of a wide range in salinity.

Mixohaline - Tolerant of a moderate range in salinity.

Stenohaline - Intolerant of changes in salinity; exists in a narrow range only.

Maturational state (code shown parenthetically) - Gonads slightly developed (1); gonads moderately developed (2); ripe (3); ripe-running (4); spent (5). Other categories included: immature (6); unable to ascertain sex (7); reabsorbed eggs (8); and decomposed or mutilated (9).

ADULT AND JUVENILE FISH

INTRODUCTION

Sampling Effort

Sampling for adult and juvenile fish was conducted during five major periods of the study. Period 1 (Jun-Aug 1983) corresponded with rising-water stage of the river; Period 2 (Sep-Oct 1983) with the peak-flood stage; Period (Nov-Dec 1983) with the declining-water stage; Period 4 (Feb-Mar 1984) with the low-water stage, and; Period 5 (June 1984) again with the rising-water stage. Sampling occurred during Periods 1-4 in all zones except the headwaters, but standard series sampling was omitted in the upper river and lower estuary zones during Period 1 because of gear and sampling constraints. Sampling in the headwaters zone began during Period 3 and was extended to include Period 5 so that fish could also be sampled during the rising-water stage in this zone.

During our field work, 649 adult fish samples were taken as follows: headwater zone (Guinea) - 33, upper river zone (Kedougou) - 89, lower river zone (Bansang) - 145, upper estuary zone (Bai Tenda) - 189 (156 in the main channel, 28 in the bolon, and 5 in the floodplain), lower estuary zone (Dog Island) - 192, and 1 at the Kekreti dam site (Appendix 2).

In the headwater zone, bottom gill net sets, 4-m seine hauls, trap net sets, and rotenone were used to collect 21, 8, 3, and 1 sample(s), respectively. Upper river samples were distributed among bottom gill net sets (42), 4-m seine hauls (42), 15-m seine hauls (3), and surface gill net sets (2). Sixty-eight bottom gill net samples were taken at the lower river zone, while the remainder of the sampling effort there consisted of surface gill net sets (64), pelagic and bottom trawl hauls (four each), shrimp try net hauls and

trap net sets (two each), and electroshocking (1 sample). Sampling in the main river channel of the upper estuary was achieved with the following number of samples taken with the designated gear: bottom gill nets - 66, surface gill nets - 65, bottom trawls - 14, pelagic trawls - 7, drifting gill nets - 3, and cast nets - 1. In the mangrove bolons of the upper estuary zone, 22 bottom and 1 surface gill net sets were made, while rotenone was used to collect 3 samples, and electroshocking was used to obtain 2 samples. In the floodplain of the upper estuary, block nets, 4-m seines, and rotenone were used to obtain 2, 2, and 1 sample(s), respectively. Lower estuary samples were collected using bottom gill nets (54), surface gill nets (51), bottom trawls (45), pelagic trawls (32), shrimp try nets (5), and 15-m seines (5). At the Kekreti dam site, the 1 sample was collected by combining multiple 15-m seine hauls.

Identification and Classification

A total of 104 species of fish were identified in samples collected in the Gambia River during 1983-1984 (Table 3). These species encompassed 16 orders and 46 families. Of these families, 14 were included in the order Perciformes, 6 in the Siluriformes, and 5 in the Rajiformes. All other orders contained fewer than 4 families. Within families, eight species of both Cichildae and Mormyridae were captured, whereas six species of Alestidae, and five species of the families Ariidae, Clariidae, Mochoeidae, and Sciaenidae were collected. Four or fewer species were sampled for each of the other families represented in our total fish catch.

These data suggest that species diversity is high in the Gambia River which is typical of many tropical rivers (Welcomme 1979), in part, because of

TABLE 3. Classification of fish species caught in the Gambia River, West Africa, 1983-1984.

Order	Family	Genus and Species	Code
Lamniformes	Carcharhinidae	*Carcharhinus limbatus* (Valenciennes)	CL
	Triakidae	*Galeorhinus galeus* (Limnaeus)	GG
Rajiformes	Dasyatidae	*Dasyatis margarita* (Gunther)	DM
	Gymnuridae	*Gymnura micrura* (Block & Schneider)	GM
	Myliobatidae	*Petromylaeus bovina* (St. Hilaire)	PT
	Rhinobatidae	*Rhinobatos cemiculus* St. Hilaire	RC
	Torpedinidae	*Torpedo marmorata* Risso	TM
Polypteriformes	Polypteridae	*Polypterus lapradei* Steindachner	PL
		Polypterus palmas Ayres	PR
Elopiformes	Elopidae	*Elops lacerta* Valenciennes	EL
		Elops senegalensis Regan	ES
Anguilliformes	Heterenchelyidae	*Pythonichthys marcrurus* (Regan)	PY
	Ophichthidae	*Pisodonophis semicinctus* (Richardson)	PD
Clupeiformes	Clupeidae	*Ethmalosa fimbriata* (Bowdich)	EF
		Ilisha africana (Bloch)	IA
		Pellonula vorax Gunther	PV
		Sardinella maderensis (Lowe)	SA
Osteoglossiformes	Notopteridae	*Papyrocranus afer* (Gunther)	PF
Mormyriformes	Mormyridae	*Brienomyrus niger* (Gunther)	BR
		Hyperopisus occidentalis (Gunther)	HO
		Marcusenius senegalensis (Steindachner)	MS
		Mormyrops breviceps Steindachner	MB
		Mormyrops deliciosus (Leach)	MD
		Petrocephalus bovei (Valenciennes)	PH
		Petrocephalus simus (Sauvage)	PC
		Pollimyrus isidori (Valenciennes)	PI
Characiformes	Alestidae	*Alestes baremose* (Joannis)	AB
		Alestes dentex (Linnaeus)	AD
		Brycinus longipinnis (Gunther)	BL
		Brycinus nurse (Rupell)	BN
		Hemigrammopetersius septentrionalis (Boulenger)	HS
		Hydrocynus brevis (Gunther)	HB
	Distichodontidae	*Nannocharax ansorgei* Boulenger	NA
	Hepsetidae	*Hepsetus odoe* (Bloch)	HD

(continued)

TABLE 3. (continued).

Order	Family	Genus and Species	Code
Cypriniformes	Cyprinidae	*Barilius senegalensis* Steindachner	BS
		Labeo coubie Rupell	LC
		Labeo senegalensis Valenciennes	LS
		Labeo toboensis Svennson	LT
Siluriformes	Ariidae	*Arius heudeloti* Valenciennes	AH
		Arius latiscutatus Gunther	AL
		Arius mercatoris Poll	AM
		Arius parki Gunther	AP
		Galeichthys feliceps Valenciennes	GF
	Bagridae	*Auchenoglanis occidentalis* (Valenciennes)	AO
		Chrysichthys furcatus Gunther	CF
		Chrysichthys nigrodigitatus (Lacepede)	CN
	Clariidae	*Clarias anguillaris* Linnaeus	CA
		Clarias lazera Valenciennes	CZ
		Clarias senegalensis Valenciennes	CR
		Heterobranchus bidorsalis St. Hilaire	HT
		Heterobranchus longifilis Valenciennes	HL
	Malapteruridae	*Malapterurus electricus* (Gmelin)	ME
	Mochoeidae	*Synodontis annectens* Boulenger	SY
		Synodontis batensoda Rupell	SB
		Synodontis gambiensis Gunther	SG
		Synodontis membranaceus St. Hilaire	SD
		Synodontis omias Gunther	SO
	Schilbeidae	*Schilbe mystus* (Linnaeus)	SM
Batrachoidiformes	Batrachoididae	*Halobatrachus didactylus* (Schneider)	HA
Atheriniformes	Belonidae	*Strongylura senegalensis* (Valenciennes)	SS
	Cyprinodontidae	*Aplocheilichthys normani* Ahl	AN
	Exocoetidae	*Hyporhamphus picarti* (Valenciennes)	HP
Perciformes	Carangidae	*Caranx senegallus* Cuvier	CX
		Chloroscombrus chrysurus (Linnaeus)	CC
		Hemicaranx bicolor (Gunther)	HE
		Trachinotus falcatus (Linnaeus)	TF
	Cichlidae	*Hemichromis bimaculatus* Gill	HC
		Hemichromis fasciatus Peters	HF
		Tilapia brevimanus Boulenger	TB
		Tilapia galilaea (Artedi)	TG
		Tilapia heudeloti Dumeril)	TH
		Tilapia occidentalis Daget	TO
		Tilapia rheophila Daget	TR
		Tylochromis jentinki (Steindachner)	TJ

(continued)

TABLE 3. (continued).

Order	Family	Genus and Species	Code
Perciformes (continued)	Eleotridae	Bostrychus africanus Steindachner	BO
		Kribia nana (Boulenger)	KN
	Ephippidae	Drepane africana (Osorio)	DA
	Gobiidae	Periophthalmus papilio (Bloch)	PK
		Porogobius schlegeli (Gunther)	PG
	Monodactylidae	Psettias sebae (Cuvier)	PA
	Mugilidae	Liza falcipinnis (Valenciennes)	LF
	Polynemidae	Galeoides decadactylus Bloch	GD
		Pentanemus quinquarius (Linnaeus)	PE
		Polydactylus quadrifilis (Cuvier)	PQ
	Pomadasyidae	Brachydeuterus auritus (Valenciennes)	BA
		Plectorhynchus macrolepis (Boulenger)	PM
		Pomadasys jubelini (Cuvier)	PJ
		Pomadasys peroteti (Cuvier)	PP
	Sciaenidae	Fonticulus elongatus (Bowdich)	FE
		Pseudotolithus brachygnathus Bleeker	PB
		Pseudotolithus senegalensis (Valenciennes)	PS
		Pteroscion peli (Bleeker)	TP
		Umbrina cirrosa (Linnaeus)	UC
	Scombridae	Scomberomorus tritor (Cuvier)	ST
	Serranidae	Epinephelus aeneus (St. Hilaire)	EA
	Sphyraenidae	Sphyraena guachancho (Cuvier)	SP
		Sphyraena sphyraena (Linnaeus)	SH
	Trichiuridae	Trichiurus lepturus Linnaeus	TL
Pleuronectiformes	Bothidae	Citharichthys stampflii (Steindachner)	CS
	Cynoglossidae	Cynoglossus senegalensis (Kaup)	CY
	Soleidae	Synaptura lusitanica Capello	SL
		Vanstraelenia chiropthalmus (Regan)	VC
Tetraodontiformes	Tetraodontidae	Ephippion guttifer (Bennett)	EG
		Lagocephalus laevigatus (Linnaeus)	LL

the large variety of habitats. Rainboth (1983) described 649 species as possible inhabitants of the Gambia River and estuary based upon a survey of literature relevant to the region. The diversity of fish in the Gambia River is greatly increased by the existence of estuarine habitat in the lower portion of the river. It is likely that an additional 50 or more species would have been collected if our sampling efforts had been extended for another year, particularly in the headwaters and lower estuary zone. Reizer (1974) reported 79 species for the Senegal River, whose drainage basin is adjacent to the northern edge of that of the Gambia River. The higher number of fish species identified during our survey of the Gambia River was probably the result of more extensive sampling, particularly in the headwater and estuarine zones.

No previously undescribed species of fish were collected during our study. However, it is possible that such species may exist in the headwaters region where no rigorous systematic studies of the fish fauna have been conducted. The upper and lower river zones have been sampled on several occasions during the past 50 years, as well as fished extensively by local populations. Previously undescribed species are less likely to be encountered in this reach of the river than in the headwater zone.

A continuing problem which plagues comparison of data on species catch and diversity among described studies and other sources of information such as personal communications is the reliance upon vernacular rather than scientific names. This problem is particularly severe in underdeveloped areas where scientific names are unknown and several languages are spoken. When integrating information from these various sources a large effort may be required to identify the species involved with one single name.

During our studies on fish and review of data from the Gambia River we encountered common names for identical species in as many as four languages: English, Mandinka, Pulaar, and Wollof. An effort was made to compile names for species we caught in as many languages as possible (Josserand 1984, Saidykhan 1984) during the study and summarize them for future use or reference (Appendix 3). Scientific names according to Rainboth (1983) are cited exclusively in this report. In addition, fishery catch survey data should utilize scientific nomenclature exclusively, to avoid ambiguity in describing catch by taxon.

Ecological Categorization and Dominance

An important charge of our studies on fish was to assess our research and findings in an ecological context as well as basic descriptive biology. Fisheries ecology may be defined as the relationship between a fish and its environment. This includes *a priori* identification of key physical, chemical, and biological factors in the environment that might affect fish or represent major effects in fish ecology. Analysis of these factors was incorporated into the other study components, the results of which were then integrated with findings on fish to describe fish and system ecology.

Fish can be classified ecologically in several different ways. One method would be according to habitats selected within the system, e.g., pelagic and benthic regions, nearshore and offshore regions, photic and aphotic zones, lotic and lentic habitats, etc. However, we chose to emphasize aspects of the transfer of materials and energy through the system in our ecological analysis of fish. This process of transfer can be studied through analysis of the feeding and metabolic relationships between fish and their

prey. Consequently, we structured our species discussions of adult and juvenile fish around a classification of fish according to their feeding habits and associated anatomical structures as described by Lagler et al. (1977). The following classes were described: generalized predators, pelagic strainers and grazers, and benthic omnivors.

Predators often have well-developed grasping mouth parts such as jaws and teeth, and active selection of prey usually occurs. Grazers tend to take food or prey such as plankton or benthic organisms in small individual bites, and some prey selectivity usually occurs. For strainers, structural adaptations such as size-selective sieve arrangements of gill rakers often occur. Benthic omnivors are bottom feeders which often indiscriminately suck mud and detritus into the mouth. Development of fleshy lips, protrusible lips and jaws, or proboscis-like structures often accompany this feeding mode.

We identified major and minor species of fish in the ecological system based on their abundance relative to each other. Abundance was defined as numerical catch, although as will be shown later there was a high correlation ($r = 0.7$–0.9) between number of fish and biomass for most catches. Another facet of our major/minor species designation was that the data bases generated from individual fish records were largest for the major species. Therefore, inferences about those species were supported by more extensive data and analyses of individual and species biology.

The major species complex was composed of 14 species of fish representing about 13% of total species diversity and which comprised the bulk of the standard series catch in numbers and biomass (Table 4). Although the grazers and strainers were numerically most abundant, the benthic omnivors comprised the major portion of the fish biomass in the freshwater portions of the river,

TABLE 4. Numbers of fish caught in standard series gill nets. R = rising water, P = peak flood, D = declining water, L = low water.

Zone	Headwaters			Upper River			Lower River				Upper Estuary				Lower Estuary				
River Stage																			%
Species	R	D	L	P	D	L	R	P	D	L	R	P	D	L	P	D	L	TOTAL	TOTAL
SA															1,813	10	18	1,841	45.3
EF											30	4	3	9	268	38	255	607	15.0
SM				6		3	33	26	24	106		2						200	4.9
CN	13	3	11	9	1	5	24	42	56	25	5	2		2				198	4.9
FE							12	7	12	3	30	26	18	9	27	1	13	158	3.9
IA											5			5	15	27	92	144	3.5
AL											9			2	56	8	64	139	3.4
PV			41				29				2	2	1					75	1.8
SG	1			16	3		8	21	6	10		3	1					69	1.7
BN	1	18	1	19	6	2	4	8		2								61	1.5
AH													1		24	2	27	54	1.3
SB								5	18	21								44	1.1
AM															16	4	19	39	1.0
GD															6		31	37	<1.0
CY											13		3	4	8		1	29	<1.0
BS	3	10	7		3	3												26	<1.0
BL	10		16															26	<1.0
PE															5	9	8	22	<1.0
CF			1	2			2	1		9	3		1	2				21	<1.0
PQ							2			1	4	2		1	8			18	<1.0
PB											1		1		5	6	1	14	<1.0
PS															4	2	8	14	<1.0
ES							3	1			1	7						12	<1.0
DA																2	9	11	<1.0
HF	1	2	3		1	3												10	<1.0
CC															2	3	5	10	<1.0
DM											1			5	4			10	<1.0
AB				8						1								9	<1.0

(continued)

TABLE 4. (continued).

Zone	Headwaters			Upper River			Lower River				Upper Estuary				Lower Estuary				
River Stage																			%
Species	R	D	L	P	D	L	R	P	D	L	R	P	D	L	P	D	L	TOTAL	TOTAL
SO			2			7												9	<1.0
PC	2		4	1		2												9	<1.0
HS		8																8	<1.0
LF							1							1	4		2	8	<1.0
PP															8			8	<1.0
AP															1	2	3	6	<1.0
BA															2	3	1	6	<1.0
GF															6			6	<1.0
ST													4		1			5	<1.0
LT	1		4															5	<1.0
PR	1		4															5	<1.0
AO	3	1	1															5	<1.0
EL										2	1		1					4	<1.0
MS			2		1	1												4	<1.0
PJ																3	1	4	<1.0
TX					4													4	<1.0
PF	1		3															4	<1.0
CS															1	2		3	<1.0
HO										3								3	<1.0
LL															3			3	<1.0
PH		1		1	1													3	<1.0
SD											3							3	<1.0
SH											2				1			3	<1.0
AD	1							2										3	<1.0
BR										2								2	<1.0
HB								1		1								2	<1.0
HD		1					1											2	<1.0
HE	2															2		2	<1.0

(continued)

TABLE 4. (continued).

Zone	Headwaters			Upper River			Lower River				Upper Estuary				Lower Estuary				
River Stage																			%
Species	R	D	L	P	D	L	R	P	D	L	R	P	D	L	P	D	L	TOTAL	TOTAL
HL	2																	2	<1.0
HX		2																2	<1.0
LC										2								2	<1.0
LS								2										2	<1.0
LX		1			1													2	<1.0
MB								2										2	<1.0
MX							2											2	<1.0
PT								2										2	<1.0
TO			2															2	<1.0
SP											2							2	<1.0
TR	2																	2	<1.0
CX															1			1	<1.0
EA																	1	1	<1.0
HT							1											1	<1.0
ME							1											1	<1.0
PA														1				1	<1.0
PL				1														1	<1.0
PM												1						1	<1.0
TF															1			1	<1.0
TH				1														1	<1.0
TJ					1													1	<1.0
TM																	1	1	<1.0
TOTAL	42	47	102	64	22	26	123	120	116	188	112	49	34	41	2,290	124	560	4,060	

particularly in the bolons. The minor species complex included 90 species of fish which were infrequently captured during this study. Our data and findings on these species were much less extensive than for major species.

The remainder of this chapter is devoted to an overview of general distributions and specific major and minor species accounts of adult and juvenile fish caught during this study. The species accounts are presented in the three ecological categories described earlier - generalized predators, pelagic strainers and grazers, and benthic omnivors. Classification of a species into a given ecological category was based on the behavior, diet, and prior descriptions of these species.

General Distributions

River Survey --

Of the 10,505 fish collected during this study, 4,028 fish were taken during standard series fishing at the primary sampling sites in each of the five zones (Table 4); the remainder were collected during supplemental fishing. Of these 4,028 fish, 149 were collected in the headwaters zone, 117 in the upper river zone, 550 in the lower river zone, 228 in the upper estuary, and 2,974 in the lower estuary. Comparison of standard series catch among zones must be made with care because of unequal fishing efforts.

In the lower estuary zone, standard series fishing was limited to sampling Periods 2-4; standard series fishing was omitted during Period 1 (rising water stage, Jun-Aug). Despite reduced fishing effort, more fish were caught in this zone than in all other zones combined. This was primarily a result of an unusually large catch (1,773 fish) of 90-130-mm juvenile *Sardinella maderensis* during the peak flood stage of the river. But even if

this particular catch is subtracted from total standard series catch in this zone, the remainder of 1,201 fish is still more than twice that of any other zone. A large number of Ethmalosa fimbriata (607 fish) were also collected in this zone. Together, Sardinella maderensis and Ethmalosa fimbriata composed 81% of the total standard series catch in the lower estuary zone. Also, the high variability in catch of these two species contributed the bulk of total difference in catch among the three sampling periods. But, based strictly upon our CPEs and standard series catch totals, it appears that abundance of fish was highest in the lower estuary relative to the other four zones of the river.

Total standard series catch (238 fish) was considerably smaller in the upper estuary zone than that recorded for the adjacent lower estuary zone (2,974 fish) or lower river zone (550 fish). But, in contrast with the lower estuary zone, no single large catch skewed the overall distribution of catch in the upper estuary zone. Also, with the exception of the rising water stage when a large number of fish were caught, catches were evenly distributed among the remaining three sampling periods or flood stages of the river. Again, standard series catch data suggest that abundance of fish in the main channel of the river was lower in the upper estuary zone than in the upper river and lower estuary zones.

Total standard series catch (550 fish) in the lower river zone was the second highest recorded for all zones. Also, the catch was quite evenly distributed among the four sampling periods. This resulted from similar-sized catches of the most abundant species made during these samplings of the river. As with the upper estuary, no single catch or species dominated the overall abundance or distribution of fish in this zone.

In the upper river zone, total standard series catch (117 fish) was the smallest recorded for any zone. Two factors affected this situation: standard series sampling was omitted during the first sampling period (rising water stage, Jun-Aug), and total standard series netting effort was reduced for this zone. Although direct comparisons of total catch cannot be made between this zone and the others, total standard series fishing effort in this zone during one sampling period was about one half that of all other zones except the headwaters. If total standard series catch in the upper river zone was doubled, it would be almost the same as total catch in the lower estuary zone, but less than catches in the lower river and lower estuary zones. Among the three sampling periods, catch during peak flood was three times that of the declining water stage and twice that of the lower water stage. These data suggest that abundance of fish in the main river channel of the upper river zone is relatively low compared with most other zones.

Standard series sampling methods in the headwaters zone varied considerably from that of the other zones, which made direct catch comparisons between this and other zones difficult. However, both abundance and diversity of fish appeared lower in the headwater zone than in other areas of the river. This was partly the result of the reduced size of the river in the headwater zone and the smaller diversity of habitats. Also, by the end of the dry season, the river was reduced to small, unconnected pools in the area of the headwater zone that was studied. This reduction in water volume and habitat undoubtedly limited the number of fish species that could survive under these conditions.

Catch comparisons among flood stages of the river and ecological zones show that the highest catch for any one sampling period occurred during peak

flood (Table 4). But as noted earlier, Sardinella maderensis comprised the bulk (72%) of this catch. If S. maderensis are excluded, total catch is reduced from 2,513 fish to 700 fish, which is comparable to catches during the other flood stages of the river.

Of the 102 species of fish collected during the study, 76 species were taken in standard series nets (Table 4). More than 100 specimens were collected for 7 species, 10-100 specimens were taken for 20 species, and 11 species were collected only once during standard series fishing. Given a single year of fishing, these data indicate that species diversity is relatively high in the Gambia River, which is typical of many tropical river systems. Welcomme (1979) described a numerical relationship between river basin area and numbers of species where: N = 0.449A, in which N = number of species and A = basin area (km^2). He calculated that the Gambia River basin should have about 90 species, which agrees with our survey data.

Quite likely, many additional species would be documented if studies were extended in the basin, since Rainboth (1983) described 649 species documented from various studies in the basin during the past 100 years. But as occurred in our standard series catches (Table 4), relatively few species would be highly abundant in relation to the others. Seven species contributed 80% to total standard series catch: Sardinella maderensis - 45%, Ethmalosa fimbriata - 15%, Shilbe mystus - 5%, Chrysichthys nigrodigitatus - 5%, Fonticulus elongatus - 4%, Ilisha africana - 3%, and Arius latiscutatus - 3%. All other species contributed less than 2% to total standard series catch.

Of the 76 species of fish collected during standard series fishing, 63 species were recorded from the lower estuary zone, 42 species from the upper estuary zone, 56 species from the lower river zone, 33 species from the upper

river zone, and 25 from the headwaters zone. Clearly, species diversity was greatest in the lower estuary zone. But it was similar among the remaining zones, especially considering the reduction is fishing effort in the upper river and headwaters zones. Species diversity among river stages within and between zones was remarkably constant; no pulse or decline was noted for periods of high or low water, in the main river channel.

Bolon/Mangrove Complex --

Sampling in the bolon resulted in the capture of 33 species of fish (Table 5), two of which (*Clarius senegalensis* and *Tilapia brevimanus*) were not caught in any other type of sampling or in any other area. *Porogobius schlegeli* was not included among the major species collected during sampling in the main river channel. However, it was the third-most abundant fish collected from the bolon. *P. schlegeli* is a gobie and likely prefers the small, protected bolons over the exposed main river channel. Five species of fish were represented in samples collected during the rising water period. Twenty-six species occurred among fish collected during the peak flood, and 21 species were found among fish samples taken during the low water period.

Although the numbers of fish species recorded in samples collected during the peak flood and low water periods were similar (26 and 21, respectively), considerable differences occurred in the abundance of the major species. Numbers of *Chrysichthus nigrodigitatus*, *Pellonula vorax*, and *Porogobius schlegeli* were greatly reduced in catches landed during low water. The difference in abundance of various species was probably related more to sampling variability than to actual differences in relative abundance. The ranked

TABLE 5. Numbers of fish caught in the upper estuary of the Gambia River near Bai Tenda during sampling in the bolon, 1983-84. R = rising water, F = peak flood, L = low water.

Fish Code*	Bolon R	Bolon F	Bolon L	Total	% Total
CN		529	145	674	44.0
PV		177	10	187	12.2
PG		150	5	155	10.1
LF		27	81	108	7.0
PA		63		63	4.1
CF	1	25	36	62	4.0
AN		35		35	2.3
TH			35	35	2.3
FE	1	22	10	33	2.2
PQ	11	8	9	28	1.8
HF		9	16	25	1.6
BO		17	2	19	1.2
HD		11	7	18	1.2
SS		13	1	14	<1
CY		9	4	13	<1
HC		11		11	<1
PY		10		10	<1
TO		7		7	<1
IA	1		6	7	<1
EL		2	4	6	<1
HB		3		3	<1
TX			3	3	<1
ES		2		2	<1
FF		2		2	<1
PM		1	1	2	<1
SM		2		2	<1
TF	1		1	2	<1
SG		1		1	<1
TB		1		1	<1
TR		1		1	<1
EF			1	1	<1
PJ			1	1	<1
PS			1	2	<1
TOTAL	15	1,138	379	1,532	

*See Table 3.

abundance of species remained relatively constant during the two sampling periods, even though their absolute abundance varied.

Chrysichthus nigrodigitatus was the most abundant species and comprised 44% of the total number of fish caught in the bolon. The abundance of *C. nigrodigitatus* in the bolon was not unexpected. A high volume detritus is discharged from the mangrove swamps and into the bolons, providing food for detritivors. Also, these fish are capable of withstanding the severe conditions (reduced oxygen, high turbidity) that often are associated with water in bolons.

Also numerous were *Pellonula vorax*, *Porogobius schlegeli*, and *Liza falcipinnis*, which comprised an additional 29% of the total fish catch in the bolon. Species which occurred in smaller numbers than the preceding ones included: *Psettias sebae*, *Chrysichthys furcatus*, *Aplocheilichthys normani*, *Tilapia heudeloti*, *Fonticulus elongatus*, *Polydactylus quadrifilis*, *Hemichromis fasciatus*, *Bostrychus africanus*, and *Hepsetus odoe*.

Of the 1,532 fish caught in the bolon, 15 (1%) were taken during the rising water period, 1,138 (74%) were netted during the peak flood stage, and 379 (25%) were caught during the period of low water. The large number of fish caught in the bolon during the peak flood was probably related to fish spawning in the bolons and along the fringing edges of the floodplains in areas that remained flooded during low tide. Fish may also have moved into the bolon during peak flood to feed on material washed off on the surrounding floodplains by the rain and ebbing tide.

Our observations indicated that both fish abundance and diversity were higher in the reaches of the bolon that were closest to the main river. High water temperatures, low oxygen, turbidity, and limited water volume in

the more distant reaches probably acted in concert to make survival difficult for all but a few species of fish. Also, the bolons did not appear to support a unique fish fauna, as all species but two captured in the bolon were also sampled in the main river. Most likely, the fish move in and out of the bolon with relative ease and frequency. This was supported by the observation of local fishermen who often set their gill nets in the mouths of the bolons to trap the fish as they moved in and out with the tidal current.

Floodplain --

Sampling on the floodplain captured 538 fish (Table 6). Of these fish, 508 were collected during the peak flood and 30 were sampled during the period of declining water. The numbers of all species collected during peak flood decreased greatly in samples taken during the period of declining water. The floodplains were not inundated during the periods of rising or low water, thus precluding the existence of fish in these areas during these stages of the river.

Ten species were recorded in samples collected during the peak flood, and seven species were noted in samples collected during the period of declining water. Species diversity and abundance was much lower on the floodplain than in the bolon. The primary reason for this was that the floodplain was entirely drained during low tide, and therefore provided only a very transient habitat for fish. For the same reason, little evidence of fish spawning was noted either by direct observation or by sampling for larval fish and eggs. The only species expected to have spawned in abundance was the mudskipper, which was well adapted to the cyclic draining and drying of the floodplain.

TABLE 6. Numbers of fish caught in the upper estuary of the Gambia River near Bai Tenda during sampling in the floodplain, 1983-84. F = peak flood, D = declining water.

Fish Code*	Floodplain F	D	Total	% Total
PV	186	6	192	35.7
PG	116	12	128	23.8
AN	69	3	72	13.4
TO	54		54	10.0
PK	46	2	48	8.9
LF	20	2	22	4.1
BO	7	4	11	2.0
CN	5		5	<1
HC	4		4	<1
HF	1		1	<1
PQ		1	1	<1
TOTAL	508	30	538	

*See Table 3.

Of the 11 species collected, Pellonula vorax and Porogobius schlegeli were most abundant and comprised 59% of the total floodplain catch. Aplocheilichthys normani, Tilapia occidentalis, Periophthalmus papilio, and Liza falcipinnis were common and comprised 36% of the total fish catch on the floodplain. The abundance of these six species of fish decreased dramatically between the peak flood and the period of declining water. The decrease in abundance of these six species accounted for 92% of the decline in fish catch between these two periods. Periophthalmus papilio was the only species of fish that was collected exclusively on the floodplain.

Most species of fish captured on the floodplain were also caught in the bolon and in the main river channel. A unique floodplain fish fauna did not exist in the area that we sampled. Those fish which did utilize the flood-

plain moved onto it during high tide and back into the bolon with the recession of water during low tide.

In general, species abundance and diversity on the floodplains was very low. This was primarily the result of low water conditions in the main river which caused the floodplains to drain almost totally during low tide. The twice-daily recession of water from the floodplain severely limited the extent to which fish could colonize the area during the flood season. Without a doubt, fish spawning was greatly reduced from previous years when the water was higher and the floodplains remained inundated for several months. During interviews with fishermen working the lower river and floodplain areas, they indicated that fish catches had declined greatly over the past two decades.

A historical description (Svensson 1933) of the lower river floodplain surrounding McCarthy Island at Georgetown, The Gambia, presented a very different picture than that which is observed today. At that time, the wet season lasted nearly 6 months and the floodplains were inundated for a large portion of that time. Svensson described the formation of several types of backwater including those created by rain and run-off water and others formed by flooding of the river. We only observed shallows (usually <1 m) that formed during high tide as the river overflowed its banks and drained with the out-going tide. Svenssen also described extensive use of weirs to trap fish as the water drained out of the floodplains with the tide and at the end of the rainy season as the flood subsided. We observed weirs on only a few occasions. Local fishermen indicated that they trapped few fish, especially in comparison with past years.

Without question, the extended drought affecting the Gambia River basin has, for the present, eliminated the floodplains and associated fishery. Although some fishermen were observed working the floodplains, the annual catch was probably insignificant in comparison with that taken from the main river channel. The reduction in fish productivity on the floodplains has undoubtedly severely reduced the seasonal availability of protein to populations living near and fishing these areas.

MAJOR SPECIES ACCOUNTS

Generalized Predators

Brycinus nurse --

Brycinus nurse is one of several species common to the six major river basins (Senegal, Gambia, Volta, Niger, Chad, and Nile) in the Soudanian region of Africa (Beadle 1981). It is an important species to some local fisheries (Welcomme 1979). Among the major species in our survey, *B. nurse* ranked tenth in abundance and thirteenth in biomass.

Spatial and temporal distribution -- Ecological zone: *B. nurse* was relatively abundant in the three freshwater zones of our study. Twenty specimens were caught in the headwater zone, twenty-seven in the upper river zone, and fourteen in the lower river zone.

River stage: *B. nurse* was caught in varying numbers during each river stage. Most fish (84%) were netted during the flood or declining flow periods; this may have been the result of movements or migrations of *B. nurse* during these periods.

Habitat: _B. nurse_ appeared predominantly in the nearshore pelagic habitat. Some gill nets which caught _B. nurse_ were set to overlap stations and/or depth strata so not all data could be analyzed in terms of habitat preference. However, of those data which were applicable, 82% (n = 55) of the _B. nurse_ were caught at nearshore stations and 80% (n = 20) were netted in the pelagic zone of the water column.

Diel period/tide cycle: Three-quarters of the _B. nurse_ taken in standard series nets were caught during the day. Presumably, this species was more active during the day than at night and this increased activity increased the probability of _B. nurse_ encountering and being captured in gill nets.

Size and condition -- _B. nurse_ ranged from 90 to 200 mm (Fig. 6). Holden and Reed (1972) noted that 200 mm is about the upper size limit for _B. nurse_. Mean length of fish in our survey was 119 mm. Size ranges of _B. nurse_ were similar for all three zones in which these fish were caught.
Mean lengths and mean condition factors were similar for _B. nurse_ caught in the headwater and upper river zones. Mean length of fish caught in the lower river zone was relatively large, but mean condition factor of fish caught in this zone was less than mean condition factor of fish netted in the other two zones. These differences in size and condition among fish from different zones may have resulted from differences in the apportionment of energy between growth and reproduction.

Sexual maturation and spawning -- Although data on gonad maturation were limited, the most positive indication of spawning was the capture of two fish (one female and one male) having spent gonads (Table 7) in the lower river

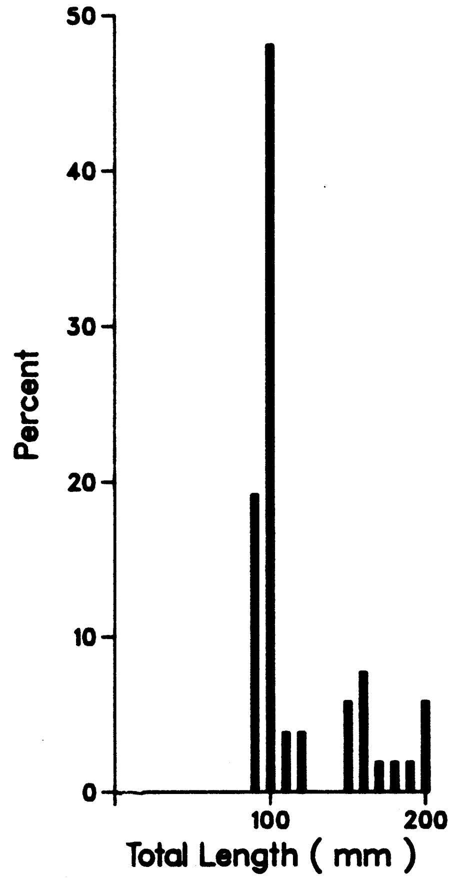


FIG. 6. Length-frequency histograms for Brycinus nurse caught in standard series samples in the Gambia River during 1983-84.

zone during the period of peak flood. In most cases, sex and approximate extent of gonad maturation was recognizable in B. nurse of sizes larger than 100 mm. Males outnumbered females by 12 to 3, although the bulk of our samples was comprised of immature fish (Table 7).

Movements and migration -- Breeding migrations have been documented for B. nurse in Lake Victoria in Kenya, while within the Central Delta of the Niger, upstream migrations during low water are thought to be related to dispersal (Welcomme 1979). The large proportion of B. nurse captured during

TABLE 7. Gonad condition and length data for Brycinus nurse caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: HW = headwaters; UR = upper river; LR = lower river. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	HW	R		1					202	202	202.0
	UR	F		2	1				105	180	133.3
	LR	R		2	1				122	153	140.3
		F		3				1	155	166	160.2
		D		1					150	150	150.0
F	HW	D			1	1			100	191	145.5
	LR	F						1	201	201	201.0
I	HW	D	17						88	103	97.3
	UR	F	1						95	95	95.0
		D	38						50	96	82.4
		L	1						162	162	162.0
	LR	R	1						95	95	95.0
X	HW	D	2						103	104	103.5
		L	1						197	197	197.0
	UR	F	11						90	165	102.5
		D	8						85	168	122.3
		L	1						189	189	189.0
	LR	R	1						145	145	145.0
		L	1						135	135	135.0

the flood and declining flow periods of our study may have reflected seasonal movements by the fish and may have been related to reproduction or dispersal.

Diet and feeding -- Virtually all (98%) of the B. nurse in our collection had food in their stomachs at the time of capture. Seeds were the dominant dietary item, although insects, molluscs, zooplankton, and detritus were also included in the contents of their stomachs. The predacious and omnivorous nature of B. nurse indicated by our data was also documented by Holden

and Reed (1972) and Welcomme (1979). Welcomme described a behavioral adaptation that allowed *B. nurse* to secure food external to the aquatic system. Fish were seen to bite at leaves of young rice plants and jostle the stems of these plants to shake rice grains into the water where they were eaten.

Chrysichthys nigrodigitatus --

Chrysichthys nigrodigitatus is found in many African river systems and is a generalized predator which occupies the bottom of main river channels during the dry season (Welcomme 1979). This species also may live in tropical lakes, occupying shallow, open muddy waters of bays where populations of molluscs and crabs provide forage (Beadle 1981).

In our study, 198 *C. nigrodigitatus* were caught in standard series gill nets. It was the fourth and sixth most abundant species captured in numbers and biomass, respectively.

Spatial and temporal distribution -- Ecological zone: *C. nigrodigitatus* were collected from four of the five ecological zones including the headwater, upper river, lower river, and upper estuary. Fish were not caught in the nearly marine lower estuary. *C. nigrodigitatus* were adapted to a wide range of environmental conditions including varying salinities, currents, and water depths. Based on numbers caught, the lower river zone appeared to be the preferred habitat for *C. nigrodigitatus* as 147 fish (74% of total) were captured in this zone. Twenty-seven *C. nigrodigitatus* were caught in the headwater zone, 15 fish were taken in the upper river zone, and 9 fish were captured in the upper estuary zone. Additional numbers of *C. nigrodigitatus*

were captured during supplementary sampling including 1 fish in the lower estuary zone and more than 700 fish in the bolon.

River stage: Numbers of C. nigrodigitatus that were gillnetted in standard series samples during each river stage were: rising water stage - 42; flood stage - 53; declining water stage - 60; and low water stage - 43. The narrow range of these numbers indicates that C. nigrodigitatus distribution was minimally affected by river stage.

Habitat: C. nigrodigitatus were caught at both nearshore and offshore stations and occurred throughout the water column. In our samples, this species was somewhat more common in catches from channel stations than shore stations, and was found predominantly in the lower and bottom depth strata. But these trends were not statistically significant; in our statistical tests, station was not a significant factor and only once was depth a significant factor (Two-way ANOVA, $\alpha = 0.05$) in the comparison of stratified catches from the upper estuary zone during the period of rising water.

Diel period/tide cycle: Catch statistics indicated that diel period and tide cycle did not influence the distribution of C. nigrodigitatus. Fish were captured during day and night periods and flood and ebb tides with no apparent connection or causality.

Size and condition -- C. nigrodigitatus taken in our nets ranged from 50 to 450 mm; mean length was 163 mm (Fig. 7). The variation in sample sizes among different zones made comparisons of fish lengths difficult, but the mean length of C. nigrodigitatus did increase in the lower ecological zones. In the headwater zone, fish had a mean length of 124 mm; in the upper river zone, mean length was 139 mm; in the lower river zone the average fish measured 161 mm; and in the upper estuary zone, mean length was 294 mm.

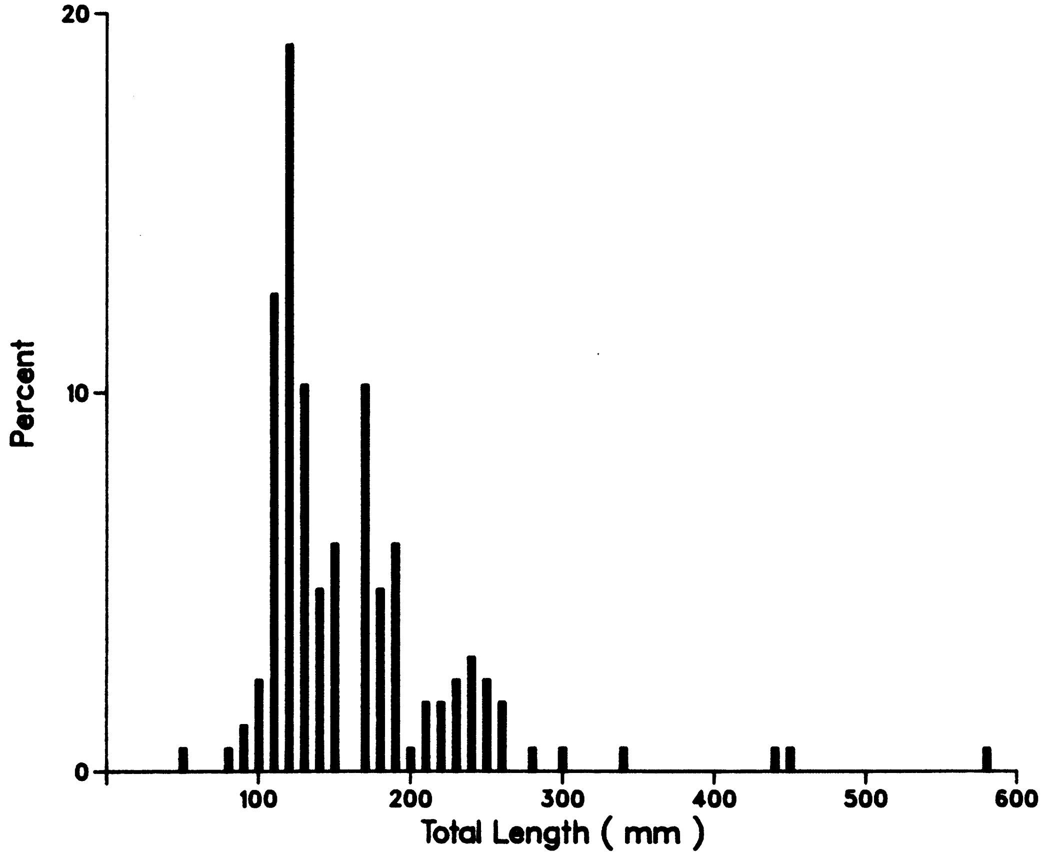


FIG. 7. Length-frequency histograms for Chrysichthys nigrodigitatus caught in standard series samples in the Gambia River during 1983-84.

However, average condition factors for *C. nigrodigitatus* were highest in the headwater and upper river zones, lower in the lower river zone, and lowest in the upper estuary zone. Evidently, factors which affected growth of *C. nigrodigitatus* were different from those which affected the condition of fish in the various zones. Competition for food probably varied among zones, and fish from different zones may have adopted different strategies for the apportionment of energy between growth and reproduction. Water current speed, which increased with distance downstream from the headwater zone, may have affected the growth and condition of *C. nigrodigitatus*. Fish in downstream zones were likely to have expended proportionately larger amounts of energy

stabilizing themselves and searching for food in the strong tidal currents than fish in the upper river zone where water currents were slower. This heightened expenditure of energy by fish living in the lower ecological zones may have reduced the amount of energy available for growth and maintenance of physical condition.

Sexual maturation and spawning -- The location and timing of maturation of *C. nigrodigitatus* was not clearly demonstrated in our data, but it appeared that spawning occurred throughout the year in several different zones (Table 8). Welcomme (1979) noted that *C. nigrodigitatus* breed actively throughout the year and build populations rapidly in "fish parks," which are masses of vegetation intentionally planted and attached to the bank or recessed into it at the mouth of channels. As the plains drain at the end of flooding season, the fish are harvested.

The most advanced stage of gonadal development observed for males in our samples was noted among fish caught in the bolon during the flood stage, and during low flow periods when a few individuals having moderately developed gonads were caught. All other males were judged to have had only slightly developed gonads. Females, however, had well-developed gonads in the upper river zone (1 fish - flood stage), the lower river zone (2 fish - rising water stage; 2 fish - flood stage; 3 fish - declining water stage; and 2 fish - low water stage), and the bolon (3 fish - flood stage). One female that had recently spawned was collected in the lower river zone during the declining river stage. Immature fish were captured in all zones and flow periods. Largest numbers of fish occurred in samples collected in the bolon (although

TABLE 8. Gonad condition and length data for *Chrysichthys nigrodigitatus* caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: HW = headwaters; UR = upper river; LR = lower river; UE = upper estuary; BO = bolon; LE = lower estuary. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

		River	Maturation stage						Length (mm)		
Sex	Zone	stage	0	1	2	3	4	5	min	max	mean
M	LR	R		4					120	435	243.0
		F		2					235	264	249.5
		D		3					173	262	203.3
		L		1					174	174	174.0
	UE	L		1					281	281	281.0
	BO	F		64	2				113	345	158.1
		L		11	1				166	289	220.9
F	UR	F				1			228	228	228.0
	LR	R		11		2			117	250	170.2
		F		3	1	2			140	246	190.1
		D		4	3	3		1	122	253	191.4
		L		3		2			130	174	141.8
	UE	R		1					450	450	450.0
		D		1					151	151	151.0
	BO	F		53	8	3			101	265	166.7
		L		6	1				122	285	185.4
I	HW	D	3						119	166	139.0
		L	14						99	163	123.7
	UR	F	1						105	105	105.0
		D	2						43	111	77.0
		L	4						112	165	135.5
	LR	R	16						57	205	125.0
		F	14						109	215	155.4
		D	19						50	180	129.6
		L	28						80	179	129.1
	UE	R	4						132	296	217.7
		F	1						63	63	63.0
		L	1						98	98	98.0
	BO	F	230						43	221	111.9
		L	97						55	243	149.5
	LE	D	1						70	70	70.0
X	HW	L	5						88	117	107.0
	UR	F	2						172	232	202.0
		L	2						115	148	131.5
	LR	D	6						125	343	194.0
		L	6						150	209	180.8
	UE	L	1						229	229	229.0
	BO	F	178						55	308	149.2
		L	29						163	288	210.5

adult gonad data suggested that little spawning occurred in the upper estuary or bolon).

A source of puzzlement was that fish of relatively very large size had indistinguishable gonads. Possible explanations for this included: (1) if _C. nigrodigitatus_ spawned more or less continuously, then many of the large fish that were captured may have spawned recently and hence had indistinguishable gonads; (2) some variation in size at maturity was expected among fish, given growth differences attributable to varying conditions associated with different zones and river stages.

Movements and migrations -- Because _C. nigrodigitatus_ were present in several zones throughout the year, it was not possible to establish patterns in their movements or migrations. Distribution of _C. nigrodigitatus_ populations appeared to form a continuum spanning several zones throughout which individuals of this species may have moved randomly.

Diet and feeding -- Specimens of _C. nigrodigitatus_ examined from our study revealed a variety of food items in their stomachs that in descending order of predominance included: detritus, crabs, vascular plants, fish, molluscs, zooplankton, shrimp, seeds, insects, algae, snails, fish larvae, and fish scales. Of 862 stomachs examined, 703 (82%) contained some food material. Most fish examined were captured in the bolon using supplementary sampling techniques. Based on numbers of fish and proportions of individuals with food in their stomachs, it is likely that the invasion by _C. nigrodigitatus_ into bolons was related primarily to feeding.

Fonticulus elongatus --

Fonticulus elongatus is a coastal fish species which commonly occurs from Senegal to the mouth of the Congo River. F. elongatus occupies waters from 15 to 45 m deep and is frequently found in estuaries and lagoons (Seret and Opic 1981). F. elongatus is a member of the family Sciaenidae, a family which is generally composed of euryhaline fishes of marine origin (Welcomme 1979). Sciaenids are gregarious and predatory and are an important group in West African fisheries (Seret and Opic 1981).

F. elongatus was the fifth most abundant species captured in standard series samples with 159 specimens caught. In biomass, they ranked third among all fish species caught.

Spatial and temporal distribution -- Ecological zone: F. elongatus were gillnetted in three ecological zones: the lower river (34 specimens), the upper estuary (83 specimens), and the lower estuary (41 specimens). This species tolerates a wide range of ecological conditions including varying salinity. Based on numbers of fish caught in standard-series sampling, it appears that the upper estuary zone was the preferred habitat. However, the number of fish caught in the lower estuary zone was under-represented because standard series sampling was not conducted during the period of rising water. Supplementary trawl samples performed in the upper and lower estuary zones yielded numerous F. elongatus, most of which were YOY.

River stage: Catches of F. elongatus did not appear to have been affected by river stage. Numbers of fish caught during the various stages were: rising water - 42, peak flood - 60, declining water - 31, and low water - 25. Even though the different river stages caused changes in the environ-

mental conditions in each zone, numbers of _F. elongatus_ in samples remained relatively consistent within zones through each river stage. This suggests that populations of _F. elongatus_ remained in a given zone despite changing environmental conditions and did not migrate in response to river stages.

Habitat: Specimens of _F. elongatus_ were collected at both shore and channel stations and in upper and lower depth strata. _F. elongatus_ did not exhibit habitat preferences in any of the three zones where they were captured.

Diel period: Nearly equal numbers of _F. elongatus_ were gillnetted in day and night sampling. This species was active and vulnerable to our sampling gear during the day and at night.

Tide cycle: Numbers of _F. elongatus_ captured in our nets were not related to tide cycle. Flooding and ebbing currents did not affect catch of _F. elongatus_ in any of the zones where these fish were collected.

Size and condition -- The 159 _F. elongatus_ specimens ranged in size from around 100 to 410 mm (Fig. 8). Seret and Opic (1981) reported that maximum size for this species is around 450 mm. The overall mean length for _F. elongatus_ in our standard series samples was 243 mm. Separated by zone, fish from the upper estuary had the greatest mean length (250 mm) followed by specimens from the lower estuary (241 mm) and those from the lower river (227 mm). This ranking was the same for overall average condition factors for _F. elongatus_ from the three zones: fish from the upper estuary zone had the highest condition factor, those from the lower estuary zone had a slightly lower condition, and fish from the lower river had the lowest condition factor. Mean length and condition factor data support the earlier supposition (based

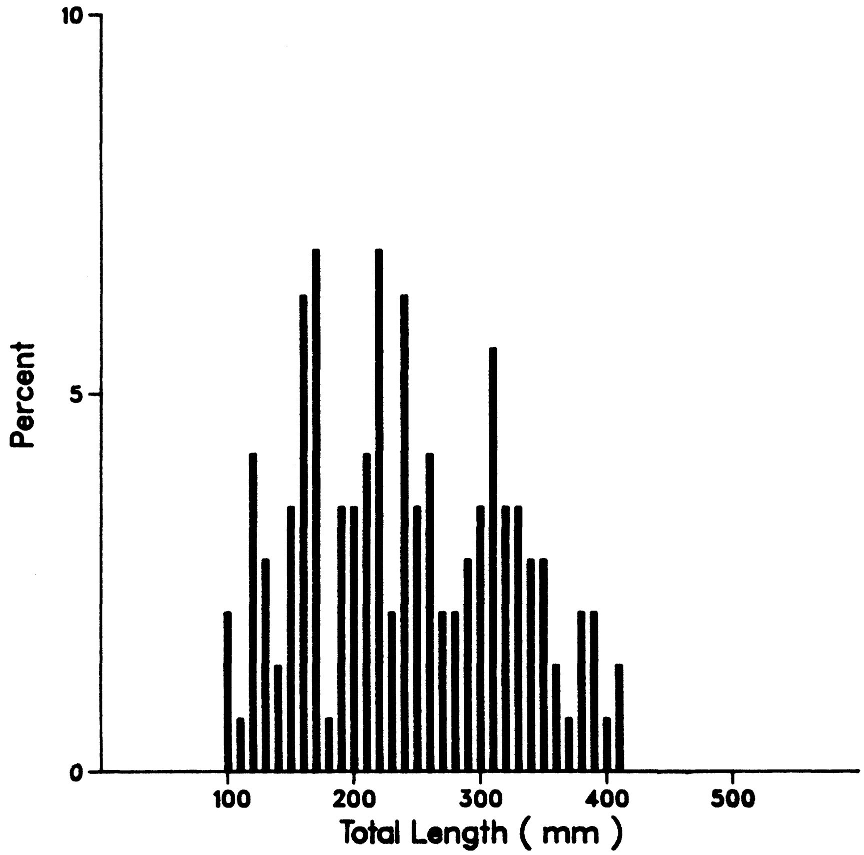


FIG. 8. Length-frequency histograms for Fonticulus elongatus caught in standard series samples in the Gambia River during 1983-84.

on numbers caught in each zone) that the upper estuary was the preferred or most favorable environment for this species.

Sexual maturation and spawning -- Based on gonad condition of adult F. elongatus and presence of immature fish, it appeared that this species spawned in the upper and lower estuary zones virtually throughout the year (Table 9). Data from supplementary trawling support this contention, because YOY F. elongatus were numerous in catches in both estuary zones during each sampling period. Spawning was not documented in the lower river zone.

TABLE 9. Gonad condition and length data for Fonticulus elongatus caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: LR = lower river; UE = upper estuary; BO = bolon; LE = lower estuary. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LR	R		6					197	255	231.3
		F		4					156	372	215.2
		D		3					251	380	297.0
		L		2					156	207	181.5
	UE	R		29					102	360	199.7
		F		10	1			1	143	330	238.2
		D		3	1				165	311	230.5
		L		6					115	186	151.8
	BO	F		9					160	288	225.6
		L		1					160	160	160.0
	LE	R		13	3				167	335	337.8
		F		16					120	305	189.0
		D		44	7				112	312	173.0
		L		25	2				110	380	165.2
F	LR	R		2					243	335	289.0
		D		3					277	310	293.3
		L			1				264	264	264.0
	UE	R		39	2				116	405	229.0
		F		8	4			1	140	390	287.0
		D		2	7			1	150	400	298.0
		L			2	2			265	350	308.2
	BO	F		3	2				250	330	281.2
		L		2	2	1			211	330	279.8
	LE	R		18	2			3	166	365	281.9
		F		20	4				115	386	225.5
		D		7	5				155	280	199.1
		L		7	11	7			150	429	243.8
I	LR	R	4						115	157	137.0
		F	32						40	174	76.7
		D	4						155	205	180.0
	UE	R	26						42	188	91.6
		F	96						32	170	64.8
		D	164						20	166	47.3
		L	135						21	185	90.9
	BO	R	1						114	114	114.0
		F	7						60	197	135.0
		L	3						132	154	145.3
	LE	R	484						20	275	86.1
		F	394						10	260	54.1
		D	64						39	160	108.3
		L	204						22	220	101.6
X	UE	R	1						220	220	220.0
		F	2						135	165	150.0
		D	2						205	245	225.0
		L	1						230	230	230.0
	BO	F	1						229	229	229.0
		L	1						160	160	160.0
	LE	R	13						169	208	186.7
		F	24						113	247	149.6
		D	4						170	198	183.2

Size at which gonads could be distinguished varied widely, but the smallest size at which some degree of gonad development (male or female) could be ascertained was about 110 mm. Maturation and spawning was not observed to occur until sizes of around 150 mm were attained. For our entire sampling effort (standard series and supplemental combined), males slightly outnumbered females (ratio = 1.2:1), while immatures dominated catches. Some F. elongatus that were deemed immature were relatively large (up to 275 mm); a portion of these fish may have had collapsed gonads.

Movements and migration -- F. elongatus did not appear to migrate in response to changing environmental conditions associated with river stage. Thus populations may be fairly distinct along the continuum of the river. However, some degree of movement and migration is probable, perhaps in connection with immigration or emigration among populations in response to population pressures, or related to spawning (lower river fish may migrate to the estuary to spawn). Though possible, such spawning migrations were not documented in our study.

Diet and feeding -- Stomachs from 2,050 F. elongatus were examined; 1,237 (60%) contained food. Of food items identified, shrimp were most numerous followed by fish and zooplankton. Less common in diets were crab, insects, algae, detritus, vascular plants, mantid shrimp, fish scales, molluscs, fish larvae, and snails. The wide range of food items selected by F. elongatus serves to explain their presence throughout the water column in both shore and channel habitats.

Availability and competition for various food items were apparently different for the three zones in which _F. elongatus_ were distributed. In the lower river zone, _F. elongatus_ fed primarily on fish, while in the upper estuary zone fish, shrimp, and zooplankton were prominent dietary items. In the lower estuary zone, shrimp were the predominant food item and zooplankton were common, while fish were relatively less important. The percentage of fish with food in their stomachs was highest in the lower estuary, lower in the upper estuary, and least in the lower river although differences among zones were not great. No distinguishing features were noted either among the diets of male, female, and immature _F. elongatus_, or among fish caught during different river stages.

Galeoides decadactylus --

Galeoides decadactylus commonly occurs to depths of 35 m along the West African coast from Cap Blanc to Angola (Seret and Opic 1981). This fish and other species of the family Polynemidae have pectoral filaments (a modification of the ventral portion of pectoral fins) which have a tactile function in murky estuarine habitats (Berra 1981). _G. decadactylus_ are fished by trawl in Senegambian waters (Seret and Opic 1981).

Thirty-seven _G. decadactylus_ were caught in our study. Relative to other major species, _G. decadactylus_ ranked fourteenth in abundance and eleventh in total biomass.

Spatial and temporal distribution -- Ecological zone: _G. decadactylus_ appeared only in samples collected in the lower estuary zone. The absence of

this species from other zones was not surprising given its preference for marine environments (Seret and Opic 1981).

River stage: G. decadactylus were captured in standard series gill nets only during the flood (6 fish) and low water (31 fish) stages of the river. Supplementary trawling yielded additional specimens (primarily immature fish) during the flood (60 fish), declining (65 fish), and low (89 fish) water periods. G. decadactylus were apparently not in the study area during the rising water river stage.

Habitat: All of the 37 G. decadactylus caught in standard series sampling were collected from nets set at nearshore stations. This suggested that currents or other factors associated with the offshore environment were avoided by this species. STATION was a significant factor in both Latin Square and Two-Way ANOVAs ($\alpha = 0.05$) for comparison of catches from the lower estuary zone during the period of low flow. Statistics addressing depth distribution of G. decadactylus were not significant but 62% of the specimens were captured in the pelagic zone.

Diel period/tide cycle: G. decadactylus were caught in day and night samples during flood and ebb tides. A behavioral pattern relating to diel and/or tide factors was not discerned.

Size and condition -- G. decadactylus caught in gill nets ranged in length from 100 to 230 mm and had a mean length of 150 mm (Fig. 9). Specimens as small as 13 mm were trawled. Maximum size for this species is reported to approach 450 mm (Seret and Opic 1981). Mean condition factors fluctuated somewhat for fish caught during different stages of river flow.

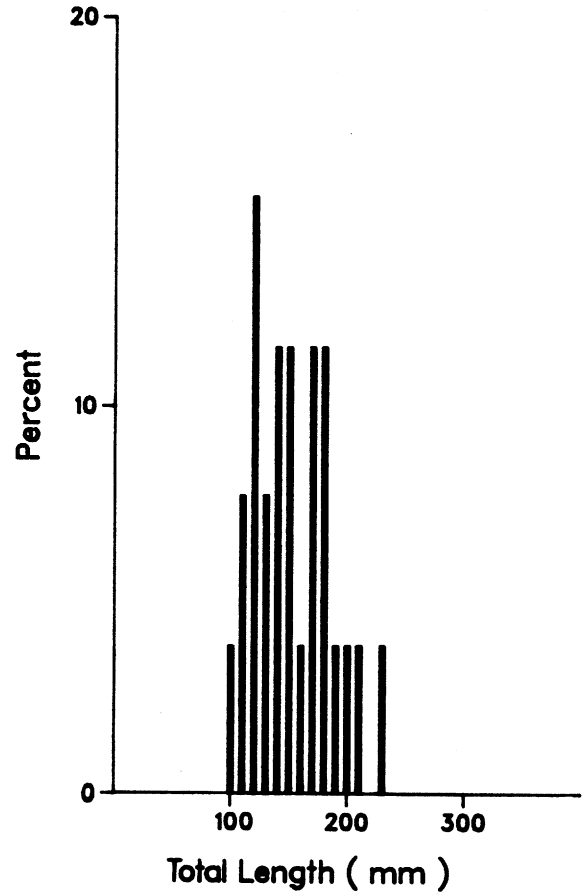


FIG. 9. Length-frequency histograms for Galeoides decadactylus caught in standard series samples in the Gambia River during 1983-84.

Sexual maturation and spawning -- Only four G. decadactylus in our samples had gonads with recognizable development - all fish were males. Of the remaining fish, 240 were immature and the maturation of 7 fish was undetermined (Table 10). One male fish captured during the period of low flow had well-developed gonads. According to Seret and Opic (1981), G. decadactylus matures at 130-140 mm, at the end of its first year. Reproduction of this species may occur year-round but peaks during the dry season.

TABLE 10. Gonad condition and length data for *Galeoides decadactylus* caught in the Gambia River during 1983-84. Sex: M = male; I = immature; X = indistinguishable. Zone: LE = lower estuary. River stage: F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LE	D		1					174	174	174.0
		L		1	1	1			189	228	207.3
I	LE	F	65						32	200	77.4
		D	62						13	180	84.6
		L	113						31	179	83.8
X	LE	F	1						125	125	125.0
		D	2						174	180	177.0
		L	4						155	176	167.0

Movements and migration -- Our data indicate that *G. decadactylus* occupy the lower estuary zone when immature. As the fish approach maturity, they probably move to coastal areas of the ocean.

Diet and feeding -- Analysis of stomach contents revealed that *G. decadactylus* fed preferentially on zooplankton, fish, and penaeid shrimp, although algae, detritus, molluscs, vascular plants, and mantid shrimp were also included in their diet. Three-quarters of the 251 specimens examined had one or more food items in their stomachs at the time of capture.

Schilbe mystus --

The most common of four schilbid species, *Schilbe mystus* is a small catfish that rarely exceeds 350 mm (Holden and Reed 1972). *S. mystus* is found in rivers of East Africa and West Africa. It is classified as a generalized

predator and occupies the open water of main river channels in the dry season, although some individuals reside all their lives in permanent floodplain lagoons (Welcomme (1979). This species is fished throughout its range. About 200 S. mystus were collected in standard series nets. It ranked third in abundance and ninth in total biomass relative to other species caught in standard series fishing.

Spatial and temporal distribution -- Ecological zone: S. mystus were caught in standard series samples from three different zones: upper river, lower river, and upper estuary. This relatively wide range of distribution indicates wide tolerance and adaptability of this species to varying environmental conditions. Most S. mystus were collected from the lower river zone (189). Nine fish were netted in the upper river while only two were caught in the upper estuary zone.

River stage: Although the greatest number of S. mystus were present in samples taken during the period of low water, this species was well represented in collections made during each of the other river stages. Thirty-three, 34, 24, and 109 fish were caught during the periods of rising water, flood, declining flow, and low water, respectively.

Habitat: S. mystus inhabited the entire spectrum of river habitats as distinguished in our study, within the zones where it was captured. These fish were caught throughout the water column and at both shore and channel stations. During the period of rising water, a significantly greater number of fish was caught at shore stations (Two-Way ANOVA, $\alpha = 0.05$) in the upper water stratum (Latin Square and Two-Way ANOVAs, $\alpha = 0.05$). During the period of low flow however, the catch at the channel station was significantly

greater (Latin Square ANOVA, $\alpha = 0.05$), and overall, no pattern of habitat preference was discerned.

Diel period/tide cycle: Based on our standard series samples, *S. mystus* were active and susceptible to our nets during day and night periods and flood and ebb tides. Because numbers of fish caught during various combinations of diel period and tide cycle were similar, the distribution and abundance of this species appeared to be unaffected by these factors.

Size and condition -- *S. mystus* were caught in standard series samples at sizes ranging from 112 to 230 mm; mean length for these fish was 143 mm (Fig. 10). The fish caught in the upper and lower river zones had similar mean lengths (140 mm), but the two fish caught in the upper estuary zone were both relatively large (190 and 203 mm). Average condition factors for fish caught in the three zones were similar.

Sexual maturation and spawning -- *S. mystus* is an anadromous species that breeds in lateral extensions of flood waters in areas where the productivity of aquatic plants and invertebrates is high. These plants and animals provide food for the young fish that hatch in these areas (Beadle 1981). Our study indicated that *S. mystus* spawned during the rising water stage of the river. Well-developed gonads were noted in six females and one male caught during this period and two females had ripe-running gonads (Table 11). It is also possible that spawning was restricted to the lower river zone. Specimens of both sexes were observed with discernible gonads at lengths as small as about 125 mm. However, immature fish measured 186 mm in some instances. In general, this species appeared to reach maturity at about 150 mm.

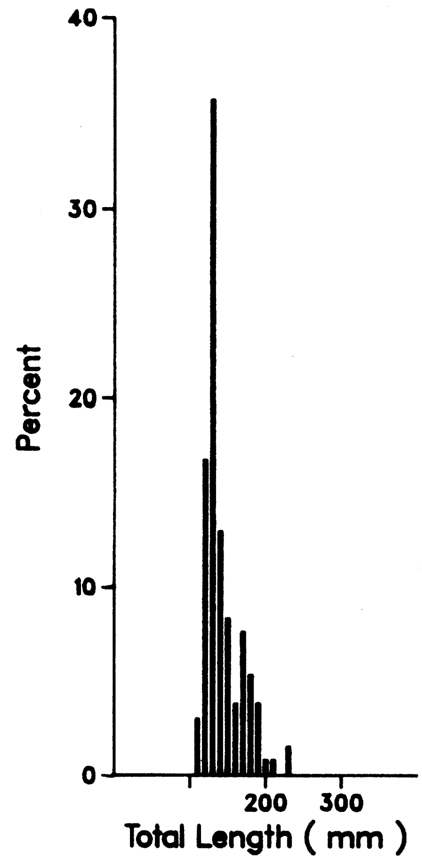


FIG. 10. Length-frequency histograms for Schilbe mystus caught in standard series samples in the Gambia River during 1983-84.

Females outnumbered males in our samples 38 to 19, but 97 immature fish were collected and comprised the bulk of the catch for this species.

Movements and migration -- S. mystus moves upstream during the low water stage to avoid saline water that penetrates the river during the dry season. Breeding migrations of 15 to 25 km from Lake Victoria up the Nzoia River in Kenya have been observed for this species (Welcomme 1979). No movements or migrations by S. mystus were evidenced in our data. Rather, the few fish captured in the upper river and upper estuary zones were probably fringe members of the main population which was concentrated in the lower river zone.

TABLE 11. Gonad condition and length data for Schilbe mystus caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: UR = upper river; LR = lower river; UE = upper estuary; BO = bolon. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	UR	F		4					125	135	128.2
	LR	R		4		1			124	157	132.8
		F		9					130	190	152.4
	UE	F		1					190	190	190.0
F	UR	F		1	1				140	182	161.0
	LR	R		7		6	2		127	225	167.2
		F		5		1			138	230	168.6
		D		4					170	183	220.5
		L		7	1				156	221	195.0
	UE	F		1					203	203	203.0
I	UR	F	1						133	133	133.0
		L	4						125	140	131.7
	LR	R	6						121	145	129.1
		F	2						126	179	152.5
		D	3						118	123	121.0
		L	78						90	186	130.6
	BO	F	2						112	135	123.5
X	UR	F	2						136	139	137.5
		L	2						118	123	120.5
	LR	R	3						122	130	126.0
		D	7						114	150	128.4

However, most of the S. mystus caught in the upper river and both fish caught in the upper estuary were netted during the period of flood. It is possible that these fish were migrating in search of floodplains suitable for breeding. The concentration of this species in the lower river during low water was evident in our data. But because most of these fish were immature, it is unlikely that they were congregating to breed.

Diet and feeding -- Holden and Reed (1972) described *S. mystus* as voracious predators and found specimens of *S. mystus* with fish in their stomachs half their own body length. Of 171 fish stomachs that we examined, 106 (62%) contained food. *S. mystus* are both predacious and omnivorous and were found to have eaten diverse food items including algae, sea urchins, crabs, fish, insects, vascular plants, and zooplankton. The wide range of habitats that these prey items occupy helps to explain the capture of *S. mystus* throughout the water column at both shore and channel stations, and during day and night. The most common food was insects which were found in stomachs of fish caught in all three zones. Insects comprised 32% of the identified food items.

Pelagic Strainers and Grazers

Ethmalosa fimbriata --

Ethmalosa fimbriata lives in mixohaline waters of West Africa. Its natural range extends from Mauritania (24 degrees north) to Angola (12 degrees south). It is both euryhaline and eurythermic throughout its range (Charles-Dominique 1982). Intraspecific competition occurs among different age groups of *E. fimbriata*, whereas at the interspecific level, competition for food resources is strong between juveniles of *E. fimbriata* and *Sardinella maderensis* (Charles-Dominique 1982). *E. fimbriata* is an extremely important species for both the commercial and artisinal fisheries in the Senegambian region (Scheffers and Conand 1976; Seret and Opic 1981; Charles-Dominique 1982; Dorr et al. 1983; Josserand et al. 1984). They are netted with beach seines, purse seines, gill nets, and cast nets (Charles-Dominique 1982), and may be taken in trawls, also. Although the bulk of the catch is consumed

fresh, some fish are dried or smoked (Scheffers and Conand 1976) and may be exported. Aside from their importance as a source of food for man, given their abundance and planktivorous nature, E. fimbriata constitute an important component of the food web (Berra 1981). Juvenile E. fimbriata are preyed upon by several fish species, birds, and crabs (Charles-Dominique 1982). The feeding habits, reproductive behavior, and migration patterns of E. fimbriata vary in different environments (Charles-Dominique 1982).

E. fimbriata ranked second in abundance and biomass among species captured in our standard series samples (603 specimens caught). These rankings testify to the relative abundance and importance of this species.

Spatial and temporal distribution -- Ecological zone: Seret and Opic (1981) described E. fimbriata as a coastal species which invades estuaries and lagoons during the dry season. E. fimbriata has been reported to have penetrated upstream in the Gambia River to 380 km (Scheffers and Correa 1971). According to Charles-Dominique (1982), immature E. fimbriata may be rare in the ocean (although data are scarce) and prefer coastal lagoons, small streams, or shallow estuary zones. Adults smaller than 250 mm may migrate upriver within the extent of the estuary, while larger adults (>310 mm) remain at sea.

Our survey documented E. fimbriata to be a prominent species in the lower estuary zone where 561 specimens were captured. The species was moderately abundant in the upper estuary zone where 46 fish were netted in standard series samples. No E. fimbriata were caught in any other zones during our survey.

River stage: *E. fimbriata* were captured in the following numbers during the indicated river stage: rising water - 30; peak flood - 272; declining flow - 41; and low flow - 264. The number of fish captured during the period of rising water was low in part because standard series nets were not set in the lower estuary zone during this period. The differences in sample size according to river stage were probably less likely attributable to flow than they were to the natural variation in distribution of *E. fimbriata* or bias of the sampling gear.

Habitat: In general, more *E. fimbriata* were caught at shore stations (73%) than in mid-river (27%). But in statistical tests, STATION was a significant factor ($\alpha = 0.05$) only in the Latin Square ANOVA for catches in the lower estuary during the period of declining flow. Nearly all specimens (97%) were caught in the upper and/or surface strata of the water column, consequently depth was a significant factor in several tests comparing catch statistics. Because *E. fimbriata* are pelagic planktivores, almost all specimens caught during our study were collected with nets set in the pelagic region of the water column. This was supported by DEPTH appearing as a significant factor in ANOVA tests (Table 12).

Diel period/tide cycle: *E. fimbriata* were collected in varying numbers in all combinations of diel period and tide cycle. No pattern could be determined from total numbers caught. However, the largest individual catches by far occurred during the day in the lower estuary - 164 fish were caught during day flood in the period of low water, and 139 fish were caught during day ebb in the period of peak flood. It may be that schooling behavior by this species is more pronounced during the day and that stationary nets have a greater chance of intercepting large schools of *E. fimbriata* during the day

TABLE 12. Summary of tests for which catch differences of Ethmalosa fimbriata were significant for the factor "DEPTH."

Zone	River stage	Value of α for given ANOVA	
		Latin Square	Two-Way
Upper estuary	Rising	0.01	0.01
	Low	-	0.05
Lower estuary	Flooding	0.01	0.05
	Declining	-	0.05
	Low	-	0.05

than during the night. TIDE was a significant (α = 0.05) factor in the Latin Square ANOVA for catches in the upper estuary zone during the period of low flow.

Size and condition -- E. fimbriata may attain 450 mm and 1 kg (Seret and Opic 1981). Average longevity is about 3 yr (Charles-Dominique 1982). The lengths of E. fimbriata caught in standard series gill nets ranged from 86 to 393 mm; mean length was 176 mm (Fig. 11). The average size of fish caught in the upper estuary (202 mm) was greater than those caught in the lower estuary (174 mm) because immature fish (<150 mm) occurred in most catches taken from the lower estuary. This reduced the mean length of fish caught in that zone; relatively few immature fish were caught in the upper estuary.

Average condition factors for fish in the lower and upper estuary zones were similar when catches from all river stages were combined. Environmental conditions in the lower estuary were relatively stable. Consequently, condition factors for fish caught in the lower estuary were similar for the various sampling periods. In the upper estuary, conditions fluctuated with

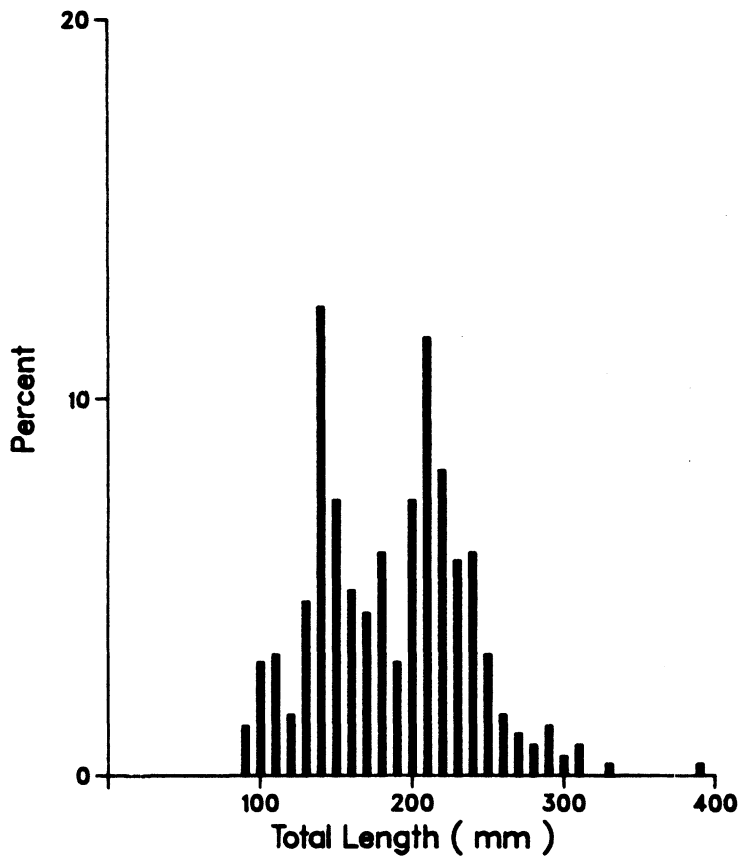


FIG. 11. Length-frequency histograms for Ethmalosa fimbriata caught in standard series samples in the Gambia River during 1983-84.

tide and season. Not surprisingly, condition factors for fish in the upper estuary showed greater variation than in the lower estuary. The highest condition factor for fish in the upper estuary occurred during the period of low flow when salt water intrusion resulted in salinities of upper estuary water that were similar to those in the lower estuary. Lowest condition factors for fish in the upper estuary occurred during the period of rising water.

Sexual maturation and spawning -- According to several investigators (Scheffers and Conand 1976; Seret and Opic 1981; Charles-Dominique 1982)

spawning by *E. fimbriata* may occur year round in estuaries, and some spawning upriver may occur during periods of salt water intrusion (Scheffers and Conand 1976; Charles-Dominique 1982). Great flexibility is shown by this species in terms of the range of environmental conditions under which it may spawn. Reproduction has been documented in salinities from 3.5 to 38% and at temperatures from 22 to 31°C (Charles-Dominique 1982). It does appear that *E. fimbriata* requires the presence of some salt water for spawning, and does not spawn in fresh water.

The following information was extracted from Charles-Dominique (1982). Female *E. fimbriata* generally mature at sizes between 170 and 210 mm, but in unfavorable environmental conditions, fish as small as 85 mm may be mature. Fecundity can approach 500 ova per gram of mature female, and female gonad weight can be 4-6% of total body weight with 24,000-190,000 eggs/gonad. During spawning, *E. fimbriata* cluster near the surface in open water at dusk, and randomly broadcast their sex products en masse.

Scheffers and Conand (1976) cited the following: in the Senegambian region, *E. fimbriata* mature at about 1.5 yr at lengths of 140 to 170 mm. Size at spawning is about 180 mm. Spawning takes place in the sea and the estuary all year but peaks in March, June-July, and October-November. In the river, females in spawning condition are present from February to March. In spring and summer *E. fimbriata* spawn in water of high salinity (>35%) as temperatures increase to 20-28°C. In autumn, reproduction occurs at low salinities (<25%) and high temperatures (28°C).

Our data on gonad maturation indicate that of the periods sampled, the most intense spawning activity by *E. fimbriata* took place in the lower estuary during the period of low water (Table 13). Our length-frequency data suggest

TABLE 13. Gonad condition and length data for *Ethmalosa fimbriata* caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: UE = upper estuary; LE = lower estuary; BO = bolon. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	UE	R		10		1		1	176	393	242.5
		F		1	1				250	261	255.5
	LE	R		3	1				227	300	273.0
		F		60					154	255	220.8
		D		1	1				211	257	234.0
		L		8	5	2	3		146	275	185.5
F	UE	R		4	2				182	261	225.0
		F		1					232	232	232.0
		D			1				259	259	259.0
		L			6				209	243	227.8
	LE	R		2		2			295	322	305.2
		F		10	6	1			201	266	231.5
		D		1	2				218	235	227.6
		L		3	4	12	1		164	310	253.5
I	BO	L	1						146	146	146.0
	UE	R	12						86	182	115.0
		L	5						113	170	144.8
	LE	R	1						165	165	165.0
		F	57						155	209	134.5
		D	22						90	173	136.5
		L	61						95	182	140.5
X	UE	F	1						285	285	285.0
		D	1						238	238	238.0
	LE	R	1						255	255	255.0
		F	61						136	245	201.3
		D	5						201	228	213.8
		L	20						143	178	157.6

that distinguishable gonads appear in E. fimbriata at lengths of 145-175 mm which agrees closely with observations of Scheffers and Conand (1976).

The sex ratio of E. fimbriata is about 1:1 throughout their range. But in our studies, the ratio of males to females (total catch) was 1.7:1. Other studies in the Gambia River (Charles-Dominique 1982) have found males to be in the minority. Scheffers and Conand (1976) found the sex ratio of 2,567 fish was 1:1.14 (males:females). The apparent discrepancy between our data (more males than females) and data of other studies may be an artifact of timing of sampling as Scheffers and Conand (1976) reported that in coastal areas male or female fish alternately dominated catch according to season. Immature fish comprised 50% of our total catch.

Movements and migration -- Our data indicated that adult E. fimbriata conducted limited migrations from the lower estuary to the upper estuary zone. These migrations may have been related to spawning (most notably during the period of rising water), but other factors could have been involved as well. Charles-Dominique (1982) noted small migrations of E. fimbriata brought about mostly by avoidance of flooding waters during rainy seasons. Scheffers and Conand (1976) found that in January, with intrusion of salt water, 2-yr-old E. fimbriata (modal length 200 mm) migrated upriver about 200 km, and smaller fish followed in March. In July-August, with the increase of freshwater flow in the river, YOY fish returned to sea. Scheffers and Conand (1976) attributed the migration to spawning movements.

Diet and feeding -- E. fimbriata feeds on phytoplankton, zooplankton, and detritus. Both pelagic and benthic feeding may occur because sand,

detritus, and benthic organisms have been found in stomachs (Charles-Dominique 1982). Little more information can be added from our stomach analysis data because planktonic food items for the most part were rendered unidentifiable soon after ingestion. Items that were categorized included algae, detritus, and zooplankton. Of the fish examined in our study, 347 of 401 (86%) had food in their stomachs. Dietary differences among male, female, or immature fish were not indicated, nor were differences apparent for fish caught in different zones or during different stages of river flow.

Scheffers and Conand (1976) argued that the feeding area for *E. fimbriata* is limited and competition from other species is greater in the river than in the ocean. Our findings support this contention; 89% of *E. fimbriata* collected in the lower estuary had food in their stomachs, while only 65% of the fish collected in the upper estuary had food in their stomachs.

During flood periods, the physical-chemical composition of water varies considerably, particularly in the amount of suspended solids. This suspended material may be stressful to fish with fine bronchial filters like *E. fimbriata* (Charles-Dominique 1982).

Ilisha africana --

Ilisha africana is a pelagic clupeid which is abundant along the tropical West African coast (Seret and Opic 1981). Although not a species that is sought by fishermen, it is taken incidentally in trawl and seine hauls; these fish are usually discarded. Of the species caught in our standard series samples, *I. africana* ranked sixth in numerical abundance and tenth in total biomass.

Spatial and temporal distribution -- Ecological zone: *I. africana* were abundant in the lower estuary zone (134 specimens netted) but scarce in the upper estuary zone (10 fish caught). Our catch data suggest that ecological conditions in the open, marine water of the lower estuary represent a favorable habitat for this species, while conditions in the upper estuary may approach the limit of their tolerance. However, supplemental fishing revealed that some *I. africana* (primarily YOY fish) penetrated to the lower river zone during the period of peak flood.

River stage: During the period of rising water, standard series samples were not taken in the lower estuary zone, and only five specimens of *I. africana* were caught in the upper estuary zone. During flooding and declining flow stages, 15 and 27 fish, respectively, were netted; all fish were caught in the lower estuary zone. Compared with other stages, sampling during the period of low flow produced the greatest number of *I. africana*: 5 from the upper estuary zone and 92 from the lower estuary zone.

Habitat: Our data documented the pelagic nature of *I. africana* as more fish were caught in nets set in the pelagic (121) than the benthic (23) strata of the water column. However, DEPTH was a significant factor in the Latin Square and Two-Way ANOVAs ($\alpha = 0.05$) only when comparing catches of the lower estuary zone during the period of peak flood.

In general, the number of *I. africana* caught at mid-river stations (87) was greater than the number caught at shore stations (57). However, statistical tests for the STATION factor showed a significant difference in catches (Latin Square ANOVA, $\alpha = 0.01$; Two-Way ANOVA, $\alpha = 0.05$) only in the lower estuary zone during peak flood when a larger number of fish were caught in shore nets than in channel nets. It appeared that some element of chance

affected whether or not nets set at a given station would intercept _I. africana_ schools because these schools moved randomly throughout the area.

Diel period/tide cycle: _I. africana_ were captured in both day and night nets in comparable numbers. This indicates that _I. africana_ were active throughout the diel period.

Catch differences did not appear to be related to tide cycle. More fish were caught during flood (90) than ebb (54) tides. However, this difference was not significant and probably was due more to chance than to some behavioral aspect of _I. africana_.

Size and condition -- In our standard series samples, 144 _I. africana_ ranged in length from 80 to 240 mm; mean length was 114 mm (Fig. 12). Maximum size for this species is around 250 mm (Seret and Opic 1981).

The mean length and condition factors of fish caught in the upper and lower estuary zones were similar. The largest fish in our collection (>170 mm) were caught in the lower estuary zone.

Sexual maturation and spawning -- Gonad maturation data for adult _I. africana_ did not reveal any clear patterns or trends in sexual maturation (Table 14). Only two females were found with well-developed gonads; both were caught in the lower estuary zone, one each during the periods of rising and declining water. No other specimens in the lower estuary zone had gonads that were more than moderately developed, and no fish in the upper estuary zone had gonads that were more than slightly developed. Quite possibly, mature adults of this species live and spawn in the open ocean. Of 1,293 _I. africana_ examined for gonad condition, 23 were males, 11 were females, 1,195 were immature, and 64 specimens were damaged.

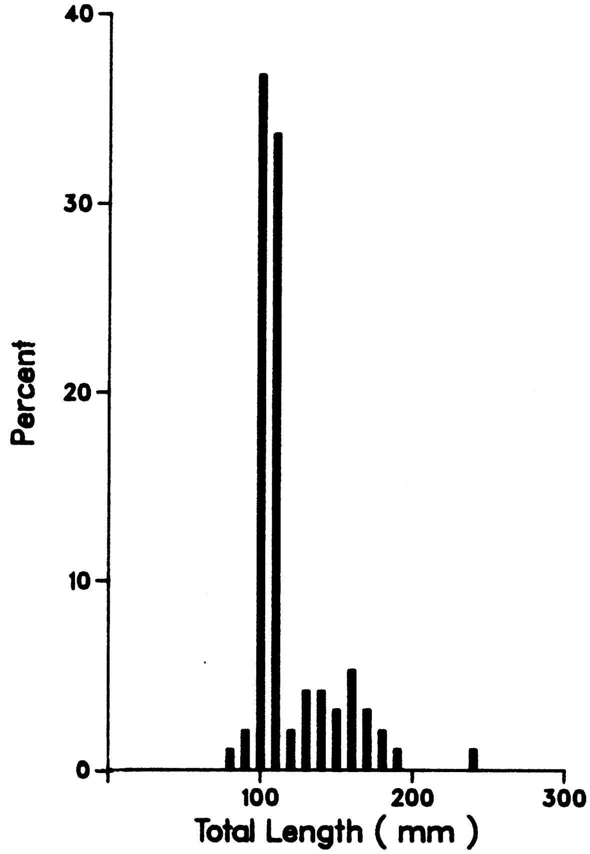


FIG. 12. Length-frequency histograms for Ilisha africana caught in standard series samples in the Gambia River during 1983-84.

Movements and migration -- Our data provided some indication that an upriver migration was undertaken by a small proportion of the population during the rising water and low water periods. Evidence for a major movement or migration by I. africana was not supported by our findings. Indirect evidence (the lack of mature adults in our samples) suggests that mostly immature fish inhabited the estuary zones of the river and upon attaining maturity, fish migrated to the open ocean along the coast.

TABLE 14. Gonad condition and length data for <u>Ilisha africana</u> caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: LR = lower river; UE = upper estuary; BO = bolon; LE = lower estuary. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LR	F		2					150	155	152.5
	UE	R		2					146	246	196.0
	LE	R		12	2				145	212	202.2
		F		1					167	167	167.0
		L		2	2				160	186	177.2
F	LR	F		2					142	160	151.0
	BO	L		1					235	235	235.0
	LE	R		4	1	1			150	186	177.2
		D				1			143	143	143.0
		L			1				165	165	165.0
I	LR	F	32						28	155	71.6
	UE	R	7						66	99	80.2
		L	5						60	166	103.2
	BO	R	1						124	124	124.0
		L	5						97	100	99.4
	LE	R	148						26	157	74.6
		F	41						36	160	87.2
		D	339						14	195	51.6
		L	597						26	157	74.6
X	LR	F	2						155	157	156.0
	UE	R	1						142	142	142.0
	LE	R	46						33	196	127.2
		F	2						99	155	127.0
		D	6						100	190	148.3
		L	7						131	244	166.2

Diet and feeding -- Examination of stomach contents revealed that *I. africana* ate a surprisingly wide variety of items for a planktivorous fish. In order of decreasing abundance, the following food items were identified from *I. africana* stomachs: shrimp, zooplankton, insects, fish, and algae. Fifty-four percent of the 1,428 fish examined had some kind of food in their stomachs.

Pellonula vorax --

Pellonula vorax is a marine species which regularly enters the mouth of the Niger and penetrates considerable distance upstream to breed (Beadle 1981). *P. vorax* ranked eighth in abundance and fourteenth in biomass among species caught in standard series sampling.

Spatial and temporal distribution -- Ecological zone: *P. vorax* were captured in standard series nets in three ecological zones including the headwater (41 fish), lower river (29 fish), and upper estuary (5 fish). Supplemental netting captured *P. vorax* in the upper river (343 fish) and lower estuary (2 fish). *P. vorax* were abundant in bolon (187 fish) and floodplain (192 fish) samples. Thus, *P. vorax* appears to survive under a wide range of environmental conditions from the headwater to lower estuary zones.

River stage: Numbers of *P. vorax* in standard series catches fluctuated and did not appear to vary in accordance with river stage. In supplementary samples, *P. vorax* catches in the upper river increased during the period of rising water, and numbers taken from the bolon were large during the period of peak flood. During the flood period in the upper estuary zone, floodplains drained by bolons supported large numbers of *P. vorax*. Most fish in supple-

mentary samples were YOY which were probably recently spawned near the areas in which they were caught.

Habitat: Based on numbers of fish caught in standard series fishing, *P. vorax* appeared to prefer the nearshore pelagic zone. No habitat preference was exhibited in supplemental fishing.

Diel period/tide cycle: *P. vorax* were most susceptible to our sampling gear (standard series and supplemental) during the day, perhaps because they were less active at night. When *P. vorax* were collected in zones with tidal effects, catches were not affected by the tide cycle.

Size and condition -- When pooled, the length range of the 807 *P. vorax* caught by all fishing methods was 20-145 mm (Fig. 13). *P. vorax* caught in the lower river and upper estuary zones were relatively large, having mean lengths of 119 and 99 mm, respectively. In comparison, fish caught in other zones (headwater, upper river, and lower estuary) and those caught in bolons and floodplains had mean lengths between 31 and 43 mm.

Condition factors were calculated for *P. vorax* caught in standard series samples. Specimens from the headwater zone had the highest overall condition factor, followed by those from the lower river zone, and those from the upper estuary zone. However, the variation in sample size among zones reduced the significance of these differences in condition factor.

Sexual maturation and spawning -- Three female *P. vorax* with well-developed gonads were among specimens collected in the upper estuary zone during flood and declining flow periods, and in the bolon during the flood period; no other fish were judged to have gonads developed beyond the moderate

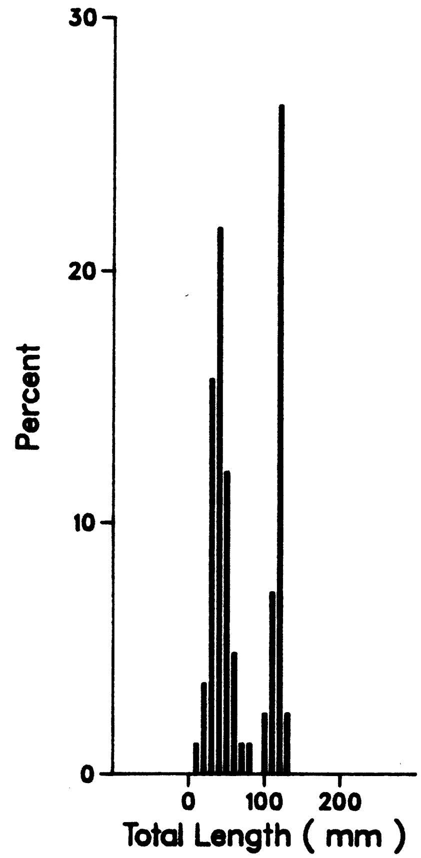


FIG. 13. Length-frequency histograms for Pellonula vorax caught in standard series samples in the Gambia River during 1983-84.

stage (Table 15). Recently spawned YOY were most prominent in samples from: (1) the upper river zone during the period of rising water, (2) the lower river zone during the period of low water, and (3) the lower estuary zone along with the bolon and floodplain areas during the period of peak flood. Some YOY P. vorax were also collected in the headwater zone during the period of declining flow. Thus, it appeared that P. vorax spawned throughout their range at different times of the year. However, the importance of the bolon/floodplain environment to the reproduction of P. vorax was clearly documented (Table 15).

TABLE 15. Gonad condition and length data for Pellonula vorax caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: HW = headwaters; UR = upper river; LR = lower river; UE = upper estuary; BO = bolon; FL = floodplain; LE = lower estuary. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage						Length (mm)		
			0	1	2	3	4	5	min	max	mean
M	LR	R		12					105	120	115.4
	UE	R		2					96	100	98.0
		F		5	1				80	100	86.5
	BO	F		7					38	92	56.7
F	LR	R		9	1				110	125	119.1
	UE	R			4				49	56	51.7
		F		1		1			105	107	106.0
		D				1			108	108	108.0
	BO	F		1	1	1			37	55	45.6
I	HW	D	41						21	57	40.8
	UR	R	102						22	53	35.2
		D	14						44	50	46.9
	LR	R	2						123	128	125.5
		L	180						19	46	32.5
	UE	R	8						39	79	49.1
		F	56						32	48	37.6
		D	4						38	55	46.5
		L	4						26	54	43.2
	BO	F	165						30	145	41.6
		L	10						45	109	64.7
	FL	F	186						28	56	39.4
		D	6						37	46	41.1
	LE	F	1						35	35	35.0
		D	1						28	28	28.0
X	UR	R	4						59	65	62.0
	LR	R	4						115	119	117.5
	BO	F	2						120	120	120.0

The smallest of the fish that had well-developed gonads was 55 mm in length. Of the fish examined for gonad condition, 27 were males, 20 were females, 780 were immatures and 10 were of indistinguishable sex (Table 15).

Movements and migration -- The extensive range of ecological conditions under which *P. vorax* were netted attests to their dispersal throughout the length of the Gambia River, presumably from an originally marine stock. Our study documented movements by fish into bolon/floodplain areas during the flooding period and movement away from these areas during the period of declining flow. These movements were most probably associated with reproduction, although feeding movements also may have occurred.

The fish caught in the lower estuary zone were small (28 and 35 mm) and may have been spawned elsewhere (perhaps in a floodplain area) and then passively transported to the lower estuary zone by currents.

Diet and feeding -- Seventy-nine percent of the *P. vorax* examined had food in their stomachs. Identified dietary items included zooplankton, fish, detritus, and insects.

Sardinella maderensis --

The following information on *Sardinella maderensis* is summarized from Seret and Opic (1981). *S. maderensis* is a pelagic species occupying coastal waters of the continental shelf to 50 m. *S. maderensis* occurs in the Mediterranean and along the west coast of Africa from Gibraltar to Angola. This species is important economically and nutritionally. It is fished using

surround nets and beach seines, and is used for consomme, fish meal, and chum for the tuna fishery.

In our survey, _S. maderensis_ was the most abundant species in standard series catches, but the extreme patchiness of their distribution was indicated by the catch in a single set of replicate nets set in the lower estuary during the period of peak flood which accounted for 84% (1,557 fish - more than twice the number of the next most abundant species) of our total catch of this species. _S. maderensis_ was well represented in supplementary trawl catches made during other times of the year, which indicated the abundance of the fish in the sampling area and their lack of vulnerability to our standard series gill nets. _S. maderensis_ ranked fourth in biomass among standard series species.

Spatial and temporal distribution -- Ecological zone: Standard series catches indicated that _S. maderensis_ were abundant in the lower estuary zone, but were not present in other zones. Supplementary samples supported this distributional finding. Salinity, food, and space requirements of this species apparently preclude its dispersal upstream of the lower estuary zone. Supplemental sampling in the lower estuary during the period of rising water (when standard series samples were not performed) indicated that _S. maderensis_ were present but not abundant in the area.

River stage: During the period of peak flood, 1,813 _S. maderensis_ (comprising 98% of the total standard series catch of this species) were netted. Ten and 18 fish, respectively, were caught during the periods of declining flow and low water. Without further study or documentation by the literature, it cannot be established if this species migrated from the ocean

and was abundant in the lower estuary during the flood period, or if the fish were abundant in the lower estuary throughout the the year, but managed to avoid our nets.

Habitat: Largest catches of S. maderensis (1,557 and 208) resulted from nets set near shore during the period of peak flood, although fish caught at channel stations outnumbered those at shore stations during the periods of declining flow and low water. These differences were not statistically significant. All S. maderensis captured during our study were netted in the upper or surface strata of the water column, reflecting the exclusively pelagic nature of this species.

Diel period/tide cycle: Most S. maderensis were caught during the day during flood tide, but the singularly large catch during the period of peak flood skewed this distribution. Fish were caught during every combination of diel period and tide cycle; subsequent statistical tests did not show significant differences among catches for any combination of the factors diel period or tide cycle. However, schooling behavior by S. maderensis may have been more pronounced during the day, thus increasing their vulnerability to day netting in comparison with night sampling.

Size and condition -- Specimens of S. maderensis ranged in size from 85 to 240 mm; the overall mean for all fish caught was about 114 mm (Fig. 14). About ten relatively large individuals (170-240 mm) occurred in samples taken during the period of peak flood. Most S. maderensis caught in gill nets were small, (90-160 mm) immature fish. The average condition factor was quite consistent for S. maderensis captured during different river stages, although

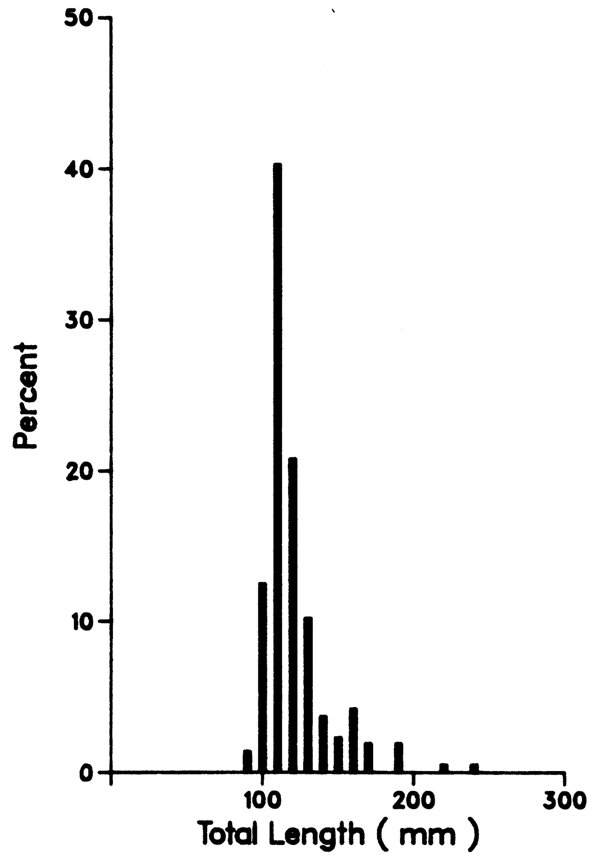


FIG. 14. Length-frequency histograms for Sardinella maderensis caught in standard series samples in the Gambia River during 1983-84.

fish caught during the period of declining flow had a slightly higher condition factor than fish caught during other river stages.

Sexual maturation and spawning -- Nearly 94% of all fish examined were immature (Table 16). A best estimate of length at maturity is 150 mm. According to Seret and Opic (1981), S. maderensis in the Senegal-Mauritanian region reproduce at depths between 10 and 50 m, and both young and adults disperse after reproduction.

TABLE 16. Gonad condition and length data for *Sardinella maderensis* caught in the Gambia River during 1983-84. Sex: M = male; I = immature; X = indistinguishable. Zone: UE = upper estuary. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LE	F		10					135	240	182.8
I	LE	R	1						32	32	32.0
		F	271						30	174	102.3
		D	10						99	156	114.6
		L	54						85	117	103.5
X	LE	F	13						93	170	143.1

Movements and migration -- Immature fish appeared to move into the estuary at sizes between 90 and 160 mm. Adults most probably reside in the ocean.

Diet and feeding -- Of the *S. maderensis* stomachs examined, 96% contained food. Identification of food items was difficult as most were digested. Algae and zooplankton were included in those items that were identified. One stomach contained a fish larva.

Synodontis batensoda --

Synodontis batensoda is a common species in fresh waters of tropical Africa and may be numerous in small dry-season pools (Holden and Reed 1972). *S. batensoda* have reverse coloration (dark ventral and light dorsal) and swim upside down to sieve food from the surface of the water and to pass water with

the highest oxygen content over their gills, because pools that they inhabit are often stagnant. Of the major species in our survey, _S. batensoda_ ranked twelfth in abundance and biomass.

Spatial and temporal distribution -- Ecological zone: All 44 specimens of _S. batensoda_ that we captured were taken in the lower river zone. The eleven most abundant species were all caught in at least two or more ecological zones.

River stage: Although no _S. batensoda_ were caught during the period of rising water, specimens were netted in the other three river stages. During the periods of peak flood, declining flow, and low water 5, 18, and 21 fish, respectively, were caught.

Habitat: Though not statistically significant, more _S. batensoda_ were caught at nearshore than offshore stations. Welcomme (1979) suggested that the upside-down swimming behavior of some _Synodontis_ species enables them to browse on root fauna while being sheltered in masses of floating vegetation at river edges. This may explain, in part, the apparent preference of _S. batensoda_ for the nearshore habitat.

Nearly equal numbers of _S. batensoda_ were caught in pelagic and demersal nets. This indicated that in the river environment (as opposed to the pools) this species does not swim exclusively upside down at the surface.

Diel period/tide cycle: _S. batensoda_ appeared to be most active and susceptible to capture in gill nets during the day and the flood tide. For an unexplained reason, no _S. batensoda_ were caught during night ebb tides.

Size and condition -- According to Holden and Reed (1972), *S. batensoda* is a small species that rarely exceeds 250 mm; most specimens are considerably less than 250 mm. Fish in our samples measured between 90 and 190 mm; mean length was 146 mm (Fig. 15). Mean condition factors fluctuated little from one season to the next.

Sexual maturation and spawning -- One female *S. batensoda* with spent gonads was caught in the lower river zone during the period of low water (Table 17). The absence of mature fish in our catches suggests that that *S. batensoda* move out of the areas sampled when breeding.

Females were considerably more numerous than males (4.2:1 ratio) in our samples. Twenty-seven fish were identified as being immature.

Movements and migration -- Most (89%) of the *S. batensoda* in our collection were caught during the dry season (periods of declining and low flow). This species may move to floodplains or other areas of the river during the rainy season and return to the river channel as flood waters subside.

Diet and feeding -- Almost all specimens of *S. batensoda* had material in their stomachs when captured; only detritus was identified during examination of stomach contents. Holden and Reed (1972) cited fine detritus and phytoplankton as primary food items for *S. batensoda*.

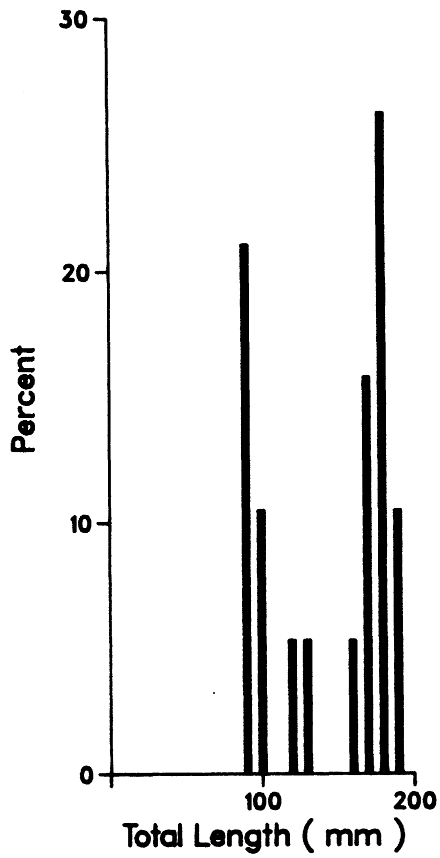


FIG. 15. Length-frequency histograms for Synodontis batensoda caught in standard series samples in the Gambia River during 1983-84.

Benthic Omnivores

Arius heudeloti --

Arius heudeloti is a coastal West African fish common from Senegal to Angola in muddy bottom habitats (Seret and Opic 1981). This species is commercially important in the Senegambian region where it is fished with trawls, gill nets, seines, and hook and line. In the Ivory Coast, a technique is being developed to raise a form of A. heudeloti commercially in lagoons (Seret and Opic 1981). A. heudeloti ranked eleventh in abundance and fifth in biomass among other species in our standard series catch.

TABLE 17. Gonad condition and length data for Synodontis batensoda caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: LR = lower river. River stage: F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LR	D		3					164	175	170.3
		L		2					169	176	172.5
F	LR	F		3					87	92	90.0
		D		5					167	189	178.2
		L		8	5			1	123	194	174.7
I	LR	D		3					90	97	94.0
		L		24					92	187	123.9
X	LR	L		7					165	185	173.5

Spatial and temporal distribution -- Ecological zone: *A. heudeloti* were relatively abundant in the lower estuary zone which agreed with the findings of Seret and Opic (1981) who described *A. heudeloti* as a common species of the Ariidae family having an affinity for marine environments. This species was rare in the upper estuary zone where only one fish was caught in standard series nets and three fish were captured in supplementary samples.

River stage: It is likely that A. heudeloti were present in the lower estuary during the period of rising water, but because standard series netting was not conducted at this juncture, this assumption was not verified by our study. Comparable numbers of *A. heudeloti* were captured during the flood (24 fish) and low water (27 fish) river stages, but only a few (3) specimens were collected during the period of declining flow. The bulk of the *A. heudeloti* population may have vacated the lower estuary zone for the open ocean during the declining flow period.

Habitat: *A. heudeloti* ranged throughout nearshore and offshore habitats in the lower estuary environment. Similar numbers of specimens were collected at both shore and channel stations.

The demersal nature of this species was strongly indicated from catch statistics which showed that in our survey, all *A. heudeloti* were captured in nets set in the demersal portion of the water column. As such, DEPTH was a significant factor in catch comparisons from the lower estuary during the period of peak flood (Two-Way ANOVA, $\alpha = 0.05$), and during the period of low flow (Latin Square and Two-Way ANOVAs, $\alpha = 0.01$).

Diel period/tide cycle: Slightly more than twice as many *A. heudeloti* were caught at night as during the day. Nighttime is the major foraging period for many members of the catfish order. However, *A. heudeloti* was also active during daylight.

The number of *A. heudeloti* netted during ebb tides (41) was greater than the number caught during flood tides (14). TIDE was a significant factor (Latin Square ANOVA, $\alpha = 0.01$) in comparison of catches from the lower estuary during the period of low flow.

Size and condition -- The 54 *A. heudeloti* caught during our study measured from 100 and 480 mm; mean length was 284 mm (Fig. 16). Four fish (including three from supplementary samples) caught in the upper estuary zone were relatively small (range: 91-203 mm; mean 146 mm) individuals. Mean condition factors fluctuated among fish caught during different river stages.

Sexual maturation and spawning -- Male *A. heudeloti* practice buccal incubation of a small number of large eggs to increase survival to the

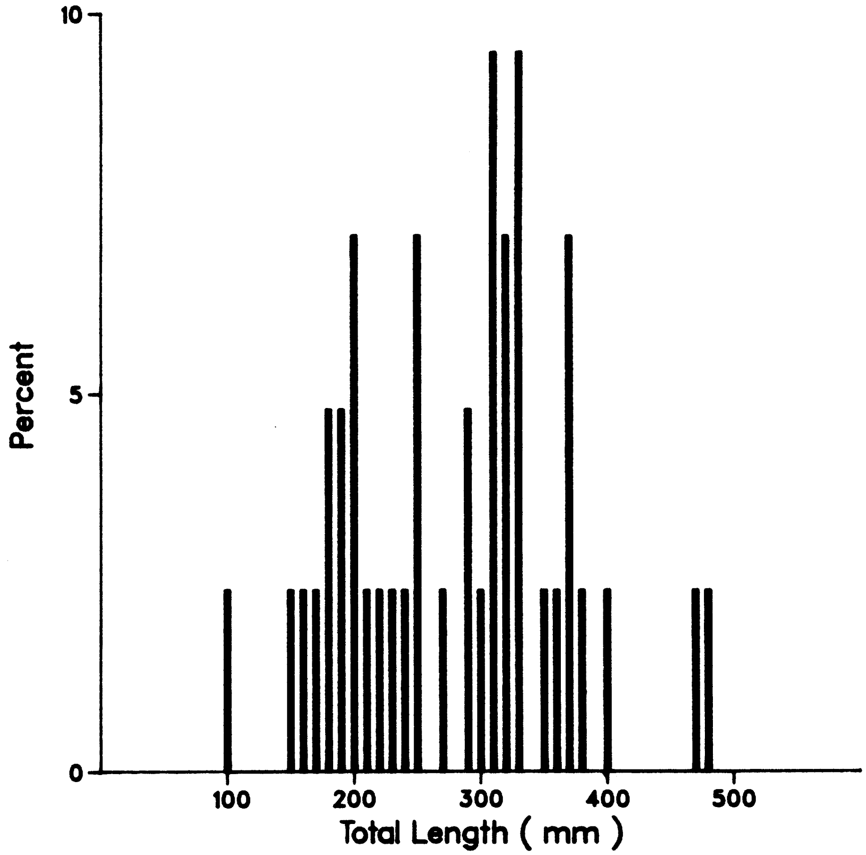


FIG. 16. Length-frequency histograms for *Arius heudeloti* caught in standard series samples in the Gambia River during 1983-84.

hatching stage (Seret and Opic 1981). One female with well-developed gonads occurred in our samples (Table 18). It was caught in the lower estuary zone during the period of low flow.

The sex ratio of male to female *A. heudeloti* was 2:1. Twenty-two immature fish and 12 fish of undetermined sex were also netted.

Movements and migration -- The relative absence of *A. heudeloti* from samples taken during the period of declining flow suggests that a migration from the lower estuary to the sea or along the coast may have occurred.

TABLE 18. Gonad condition and length data for Arius heudeloti caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: UE = upper estuary; LE = lower estuary. River stage: F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LE	F		5					332	400	365.8
		L		5					205	330	287.0
F	LE	F		2					312	380	346.0
		L		2		1			315	470	370.0
I	UE	D	3						91	160	127.3
	LE	F	10						101	310	203.0
		D	2						135	147	141.0
		L	7						173	265	205.1
X	UE	L	1						203	203	203.0
	LE	F	3						322	355	342.3
		D	2						186	332	259.0
		L	6						243	475	313.8

Other Arius species also appeared to have vacated the lower estuary zone during the period of declining flow (see A. latiscutatus and A. mercatoris).

Diet and feeding -- A. heudeloti were largely piscivorous. Fish was the most common food item found in stomachs. Other items consumed included shrimp, crabs, fish scales, and zooplankton. Food was found in 76% of the fish stomachs examined.

Arius latiscutatus --

Members of the family Ariidae are essentially estuarine, although some species are clearly marine and others are found only in fresh water. In the tropical Atlantic, only the genus Arius is represented (Seret and Opic 1981).

Arius latiscutatus was the seventh-most abundant species collected in our standard series samples. The total biomass of *A. latiscutatus* was greater than that of any other species.

Spatial and temporal distribution -- Ecological zone: Most (92%) of the *A. latiscutatus* in our samples were netted in the lower estuary zone. The rest (8%) came from samples taken from the upper estuary zone. Based on these data, the lower estuary zone was clearly the preferred habitat for *A. latiscutatus* among the environments examined during our study.

River stage: Representation of *A. latiscutatus* in our samples varied with river stage. During the period of rising water, 9 fish were caught in the upper estuary zone (standard series sampling was not conducted in the lower estuary zone). Fifty-six and 9 *A. latiscutatus* were captured (all in the lower estuary zone) during the periods of peak flood and declining water respectively. Finally, 66 specimens (2 from the upper estuary and 64 from the lower estuary) were taken during the period of low flow.

Environmental conditions in the upper estuary appeared unsuitable for *A. latiscutatus* during the periods of flood and declining flow. In the lower estuary zone, *A. latiscutatus* were considerably more abundant during the flooding and low water river stages than during the period of declining water. A similar pattern of varying seasonal abundance was observed for other *Arius* species (see *A. heudeloti* and *A. mercatoris*). As with *A. heudeloti*, *A. latiscutatus* may undertake a seaward migration and were thus relatively less numerous in our sampling area during the period of declining flow.

Habitat: *A. latiscutatus* caught in the lower estuary zone did not indicate a preference between shore and channel habitats. But in the upper

estuary zone, 10 of 11 fish were captured at channel stations. The Latin Square ANOVA indicated a significantly (α = 0.01) greater number of *A. latiscutatus* were caught at channel stations than at shore stations in the upper estuary zone during the period of rising water.

A. latiscutatus were caught almost exclusively in the demersal strata of the water column. All *A. latiscutatus* caught in the upper estuary zone were taken in demersal nets. In the lower estuary, the number of fish caught near the bottom was significantly greater than the number caught near the surface during the period of peak flood (Latin Square and Two-Way ANOVAs, α = 0.01) and during the period of low flow (Two-Way ANOVA, α = 0.05).

Diel period/tide cycle: More *A. latiscutatus* in our samples were caught during the night (64%) than during the day (36%). The sensory barbels of these catfish allow them to search for food in darkness and help to explain the nocturnal activity of *Arius*.

Variation in *A. latiscutatus* catches did not appear to have been connected with the tide cycle. Fish were caught during both flood and ebb tides, and during all combinations of diel period and tide cycle.

Size and condition -- Compared with other major species, the mean length and mass of *A. latiscutatus* were relatively large. A length range of 160-670 mm and mean length of 333 mm were recorded for this species (Fig. 17). Individuals that ventured upriver to the upper estuary zone were generally larger (range: 270-670 mm; mean: 388 mm) than *A. latiscutatus* caught in the lower estuary zone (range: 160-570 mm; mean: 328 mm). Mean condition factors were similar for fish from either zone.

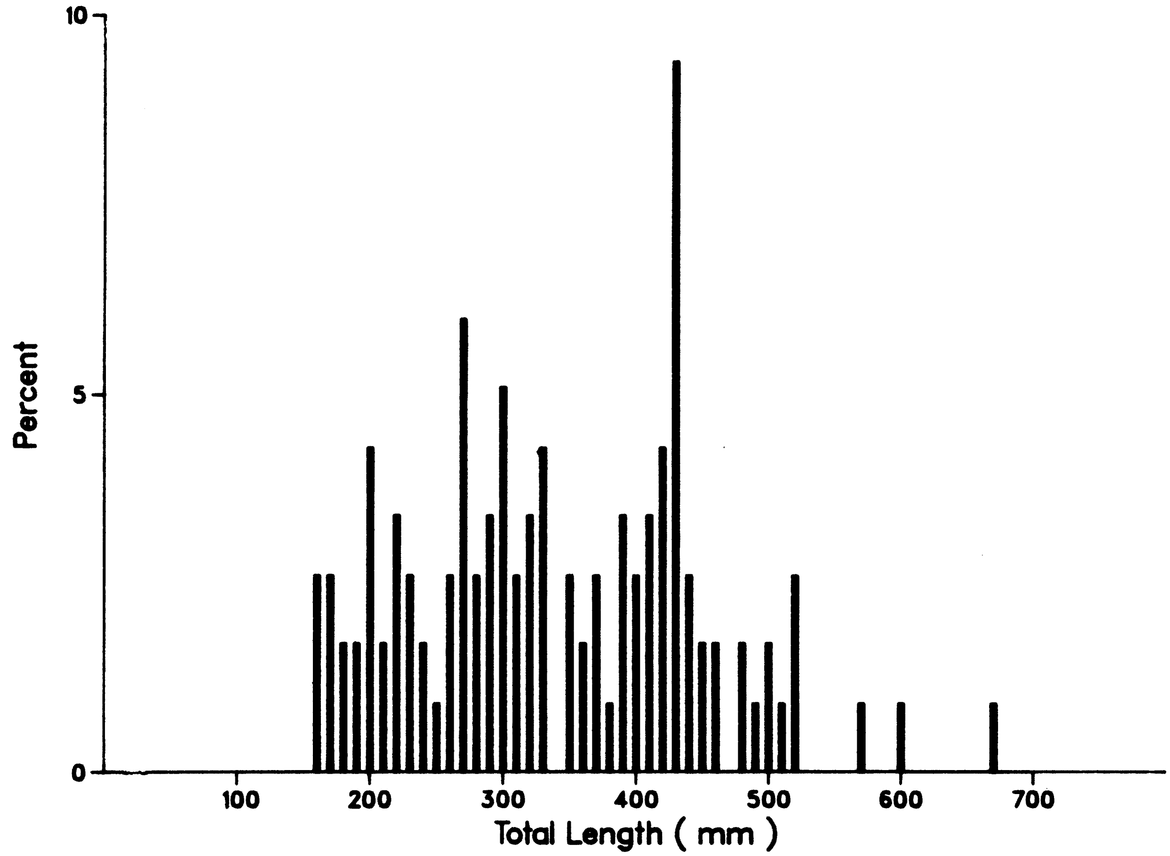


FIG. 17. Length-frequency histograms for _Arius latiscutatus_ caught in standard series samples in the Gambia River during 1983-84.

Sexual maturation and spawning -- Gonad maturation data indicated that _A. latiscutatus_ spawned in the lower estuary zone during and between the periods of rising water and peak flood. Well-developed gonads were noted in two males during the low-water period; one female with ripe-running and four with spent gonads were recorded during the period of rising water. Twelve females with spent sex products were among fish sampled during the period of peak flood (Table 19).

TABLE 19. Gonad condition and length data for _Arius latiscutatus_ caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: UE = upper estuary; LE = lower estuary. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage						Length (mm)		
			0	1	2	3	4	5	min	max	mean
M	UE	R		8					267	597	367.2
		L		1					346	346	346.0
	LE	R		9					190	530	397.2
		F	14	2					210	520	361.1
		D		2					189	410	299.5
		L	12	7	2				179	570	360.8
F	UE	L		1					670	670	670.0
	LE	R		1			1	4	355	535	441.6
		F		6	3			12	271	480	391.6
		D		1					135	135	135.0
		L		6	1				203	475	320.2
I	UE	R	3						90	114	98.6
	LE	R	12						70	312	186.2
		F	8						155	375	260.1
		D	5						135	218	168.2
		L	20						160	295	217.8
X	LE	R	2						235	420	327.5
		F	10						266	445	347.1
		D	7						266	437	366.8
		L	7						290	446	333.0

Some sexual development was detectable in fish as small as 135 mm (female) and 179 mm (male), but maturation and spawning probably did not occur until fish were considerably larger than these sizes. In our samples, _A. latiscutatus_ with advanced stages of gonad development were generally larger than 350 mm.

The ratio of males to females was about 1.6:1 for _A. latiscutatus_ in our survey. Forty-eight immature fish and 26 specimens of indistinguishable sex were collected.

Movements and migration -- Of the zones surveyed, *A. latiscutatus* principally occupied the lower estuary zone. However, a relatively small number of fish migrated upstream to the upper estuary zone during the periods of low and rising water. During the period of declining flow, most of the *A. latiscutatus* population residing in the lower estuary zone apparently migrated to sea. These migrations were probably not related to spawning but may have been associated with feeding.

Diet and feeding -- A wide variety of food items was identified from examination of *A. latiscutatus* stomachs. Fish was the most frequently observed item followed by crabs, shrimp, vascular plants, zooplankton, molluscs, fish scales, algae, opheuroids, detritus, fish eggs, seeds, holothuroids, insects, and snails. Most prey consumed by *A. latiscutatus* were available in both upper and lower estuary zones. In the lower estuary zone, the availability of some food items seemed to vary seasonally, with the greatest variety available during the periods of rising and flooding water; a less varied diet occurred in stomachs of *A. latiscutatus* collected during the periods of declining and low water. Of 167 stomachs examined, 128 (77%) contained food.

Arius mercatoris --

Along with *Arius latiscutatus* and *A. heudeloti*, *A. mercatoris* was the third *Arius* species which numerically qualified as a major species in our survey. *A. mercatoris* ranked thirteenth in abundance and seventh in biomass.

Spatial and temporal distribution -- Ecological zone: The lower estuary was the only zone from which *A. mercatoris* was collected. This zone was also where *A. latiscutatus* and *A. heudeloti* were concentrated.

River stage: *A. mercatoris* was represented in samples collected during every river stage in which standard series sampling was conducted in the lower estuary zone. Most specimens were collected during the flood and low flow stages. As with the other species of *Arius*, relatively few *A. mercatoris* were sampled during the period of declining flow.

Habitat: *A. mercatoris* appeared to prefer offshore habitat to nearshore habitat, although this preference was not reflected as statistically significant during our analysis of catch data. Preference for demersal rather than pelagic habitat was more evident. Of 38 specimens, 34 were caught in demersal nets and DEPTH was a significant factor for catch comparisons between the periods of peak flood and low flow (Latin Square ANOVAs, $\alpha = 0.05$).

Diel period/tide cycle: Day and night catches of *A. mercatoris* were generally comparable even though numbers of fish caught fluctuated from one sampling period to the next, and no *A. mercatoris* were caught at any river stage during day flood. Catches were 3.75 times greater during ebb tides than during flood tides. A similar proportion was noted for *A. heudeloti*. It is possible that the availability of some types of food sought by *A. heudeloti* and *A. mercatoris* varied with the tide cycle.

Size and condition -- A size range of 170 to 540 mm and a mean length of 269 mm made *A. mercatoris* one of the larger species caught during our study (Fig. 18). Of the specimens of *A. mercatoris* captured during the different river stages, those caught during the period of declining flow had the small-

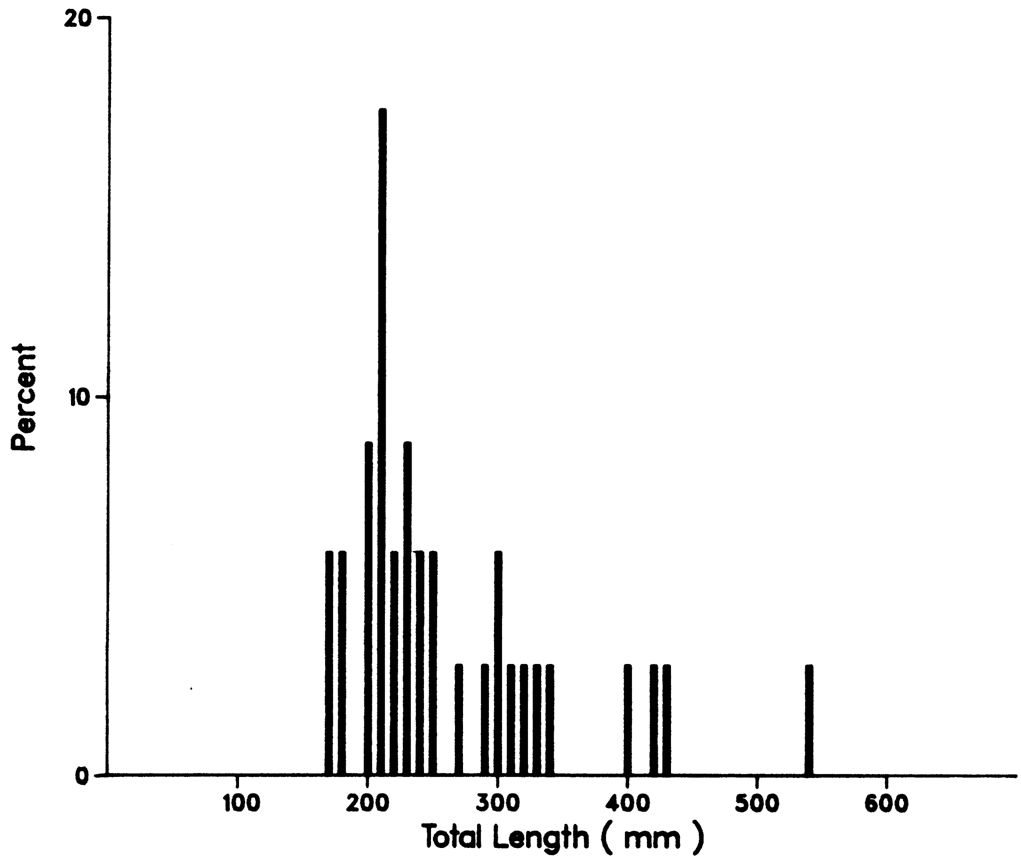


FIG. 18. Length-frequency histograms for Arius mercatoris caught in standard series samples in the Gambia River during 1983-84.

est mean length and lowest condition factor. It may be that these immature fish did not participate in a migration to the sea during the period of declining flow.

Sexual maturation and spawning -- A. mercatoris specimens with well-developed gonads were not collected in either standard series gill nets or supplemental trawls (Table 20). This provides indirect evidence that gonadal maturation and spawning may have occurred somewhere outside our study areas or possibly between sampling periods.

TABLE 20. Gonad condition and length data for *Arius mercatoris* caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: LE = lower estuary. River stage: F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	LE	F		10					155	433	209.3
		L		2	1				305	415	352.6
F	LE	L		2					205	215	210.0
I	LE	F	14						170	400	252.8
		D	6						141	189	173.8
		L	9						181	239	212.8
X	LE	F	1						162	162	162.0
		D	1						210	210	210.0
		L	3						243	539	343.0

The breakdown by sex for adult *A. mercatoris* in our collection was skewed heavily toward the males (6.5:1), but the sample size was relatively small and it seems unlikely that this ratio represents the numerical relation between the sexes for the entire estuarine population. Immature fish comprised over one-half of the *A. mercatoris* captured.

Movements and migration -- In the lower estuary zone, the absence of mature fish and the reduced numbers of *A. mercatoris* during the period of declining flow support our hypothesis of a seaward migration by this and perhaps other species of *Arius*.

Diet and feeding -- Seventy-three percent of the *A. mercatoris* specimens had food in their stomachs. Fish were the most commonly eaten item.

Crabs, detritus, squid, shrimp, and zooplankton were also found in stomachs that were examined.

Synodontis gambiensis --

The family Mochokidae is endemic to tropical Africa and the Nile Valley (Berra 1981). *Synodontis gambiensis* is common in fresh waters of the Senegambia region where it and other synodontids comprise an important component of the fisheries. In our survey, *S. gambiensis* ranked ninth in numerical abundance and eighth in biomass of the species caught in the standard series catch.

Spatial and temporal distribution -- Ecological zone: Specimens of *S. gambiensis* were netted in four ecological zones from the headwaters to the upper estuary. Most *S. gambiensis* were collected from the upper river zone (19 fish) and lower river zone (45 fish), indicating that these areas were the preferred habitat for this species. However, presence of fish in samples from the headwater zone (1 fish) and upper estuary zone (4 fish) indicate the tolerance of *S. gambiensis* to a wide range of environmental conditions.

River stage: *S. gambiensis* were caught during all four river stages in the lower river zone. In the other zones where *S. gambiensis* was not captured during every river stage, it was not clear if the presence or absence of fish during a given river stage was the result of fish movements into or out of the sampling areas, or was simply related to the chances of catching this species in zones where it was somewhat rare. The single fish netted in the headwater zone was caught during the period of rising water. In the upper river zone, fish were captured during the periods of peak flood (16 fish) and declining

water (3 fish). The presence of *S. gambiensis* in the upper estuary zone was documented during periods of peak flood (3 fish) and declining flow (1 fish).

Habitat: *S. gambiensis* ranged throughout nearshore and offshore habitats without showing a preference for either habitat. This species was more selective with regard to its position in the water column however. Ninety-six percent of all *S. gambiensis* in our survey came from samples collected from demersal habitats and as such, DEPTH was a significant factor in several statistical catch comparisons (Table 21).

TABLE 21. Summary of tests for which catch differences of *Synodontis gambiensis* were significant for the factor "DEPTH."

Zone	River stage	Value of α for given ANOVA	
		Latin Square	Two-Way
Lower river	Rising	0.01	0.01
	Flooding	0.01	0.05
	Declining	--	0.05

Diel period/tide cycle: Neither diel period nor tide cycle clearly influenced catches of *S. gambiensis*. In zones that were far enough away from the ocean to be unaffected by tide cycles, *S. gambiensis* were caught during hours of light and darkness in comparable numbers. In zones which experienced tidal influence, *S. gambiensis* were netted during all combinations of diel period and tide cycle.

Size and condition -- Sixty-nine *S. gambiensis* were measured and ranged in length from 109 to 296 mm; mean length was 208 mm (Fig. 19). Mean lengths of fish calculated according to ecological zone were not dramatically differ-

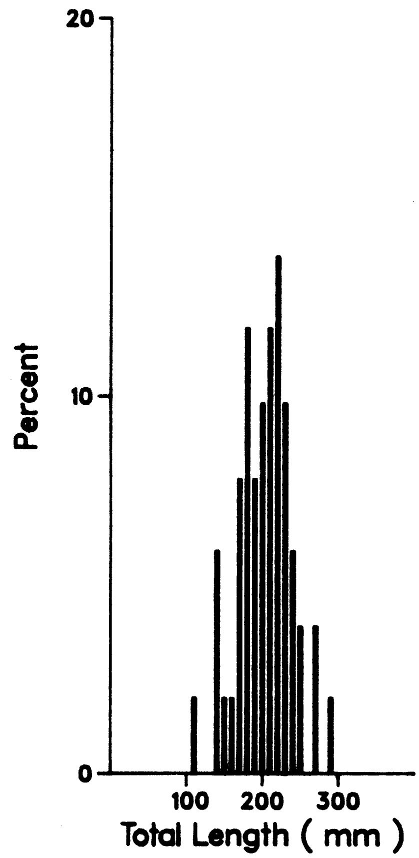


FIG. 19. Length-frequency histograms for Synodontis gambiensis caught in standard series samples in the Gambia River during 1983-84.

ent from each other. Overall mean condition factors were also similar for fish collected in different zones.

Sexual maturation and spawning -- Four females with spent gonads were caught in the lower river zone, one during the period of rising water and three during the period of low flow (Table 22). No other fish in our samples had gonads that were developed beyond the moderate stage. Size at sexual maturity was estimated to be 180-200 mm.

Of all S. gambiensis collected, females slightly outnumbered males by a ratio of 1.2:1. Immatures comprised 22% of the catch.

TABLE 22. Gonad condition and length data for *Synodontis gambiensis* caught in the Gambia River during 1983-84. Sex: M = male; F = female; I = immature; X = indistinguishable. Zone: HW = headwaters; UR = upper river; LR = lower river; UE = upper estuary; BO = bolon. River stage: R = rising; F = flood; D = declining; L = low. Gonad maturation stages: 0 = indistinguishable; 1 = slightly developed; 2 = moderately developed; 3 = well developed; 4 = ripe-running; 5 = spent.

Sex	Zone	River stage	Maturation stage 0	1	2	3	4	5	Length (mm) min	max	mean
M	HW	R			1				230	230	230.0
	UR	F		2	2				165	181	172.7
	LR	R		1					212	212	212.0
		F		8					165	220	194.1
		D		3					223	250	234.3
		L		1					213	213	213.0
	UE	F		4					199	235	217.2
	BO	F			1				260	260	260.0
F	UR	F			6				154	200	177.6
	LR	R		2				1	220	290	248.3
		F		5	1				182	265	229.3
		L		2	2			3	207	296	244.7
	UE	F		5					195	230	209.6
		D			1				276	276	276.0
I	UR	F	1						109	109	109.0
		D	3						136	155	142.6
	LR	R	4						178	215	198.2
		F	1						225	225	225.0
	UE	F	8						167	270	217.7
		D	1						195	195	195.0
X	UR	F	2						192	220	206.0
		D	2						135	197	166.0
	LR	D	1						217	217	217.0
		L	5						194	259	218.4
	UE	D	3						210	242	225.6

Movements and migration -- As expected, most movement and migration by *S. gambiensis* occurred during the rainy season when fish moved into flooded areas to feed and breed. Welcomme (1979) noted that some species of *Synodontis* are among a group of species that invades floodplains in a second wave following the initial cohort of species that arrive and depart the floodplains during the first phases of flooding. After the rainy season, some *Synodontis* may remain on floodplains living in pools, lagoons, and swamps until the next flood (Welcomme 1979).

Diet and feeding -- *S. gambiensis* are carnivorous bottom feeders which engage in demersal foraging. Juvenile *Synodontis* were labeled "Aufwuchs" browsers by Welcomme (1979). Detritus was the most abundant item in stomachs of *S. gambiensis* examined in our study, although insects, molluscs, vascular plants, fish, and seeds were also commonly noted. Somewhat less common in their diet were algae, penaeid shrimp, and mantid shrimp. Most (88%) of the 86 specimens examined had fed recently prior to capture.

NON-STANDARD SERIES SAMPLING

Supplementary or non-standard series sampling produced 6,927 fish representing 94 fish species (Table 23). Of these 6,927 fish, 1,532 were caught during sampling in the bolon (Table 5) and 538 were captured during sampling on the floodplain (Table 6). The majority of these fish were major species that were also taken in standard series fishing. These species included: *Brycinus nurse*, *Chrysichthys nigrodigitatus*, *Fonticulus elongatus*,

TABLE 23. Numbers of fish caught by river zone and stage during non-standard-series sampling in the Gambia River, 1983-84. R = rising water, F = peak flood, D = declining water, L = low water.

	Headwaters			Upper River				Middle River		Lower River				Upper Estuary				Middle Estuary	Lower Estuary					%
	R	D	L	R	F	D	L	R	D	R	F	D	L	R	F	D	L	L	R	F	D	L	TOTAL	TOTAL
FE										1	31	4	2	55	95	172	107	20	547	19	547	253	1,853	26.8
IA											38			5			23	8	217	26	485	593	1,395	20.1
PV		41		106		14			8	2		9	180	12	62	4	3			1	1		443	6.4
HS		8		237		39	30		23														337	4.9
PS																			151	46	56	74	327	4.7
PE											24						2	1	163	1	78	35	304	4.4
GD																				62	65	120	247	3.6
SA																			1	107	8	53	169	2.4
BL	22		32	54			41																149	2.3
EF																	9		10	1	12	116	148	2.3
TP																			23		15	80	118	1.7
AL														3			2		29	7	12	54	107	1.5
LF										1							1		2	98	1	3	106	1.5
BN	1	20	1		1	46	2	1	30	1													103	1.5
CN	21	5	21		1	2	6			10		1	29		1	1	3				1		102	1.5
BS	15	18	9	4		13	6		27														92	1.3
BA											2								1		12	67	82	1.2
SM					6		6	1					63										76	1.1
TX	11					62																	73	1.1
PQ												1			2	11	1	2	30	1	8	6	62	<1.0
CY								1						4	3	7	4		14	9		5	47	<1.0
CC																					28	17	45	<1.0
DA																			3	9	18	11	41	<1.0
SG	2				4	5				3			6		14	4							38	<1.0
SB													36										36	<1.0
PB																1			3	18	9	3	34	<1.0
AM																				9	7	17	33	<1.0
AH																3					4	20	27	<1.0
PJ																				24	2	1	27	<1.0
HF	2	3	3	3		5	3	4	3	1													27	<1.0
TO			2	21						1										1			25	<1.0
DM														1			4		6	3	2	1	17	<1.0

(continued)

TABLE 23. (continued).

	Headwaters			Upper River				Middle River		Lower River				Upper Estuary				Middle Estuary	Lower Estuary					%
	R	D	L	R	F	D	L	R	D	R	F	D	L	R	F	D	L	L	R	F	D	L	TOTAL	TOTAL
CF		1	1										5	2	2	1	2						14	<1.0
PC	2		10				2																14	<1.0
SC			2				12																14	<1.0
PP											1								8	1	2		12	<1.0
EG																				1	10		11	<1.0
AN				10																			10	<1.0
MD	6							1					2										9	<1.0
PH		8				1																	9	<1.0
HD		2				4	1														1		8	<1.0
PG																4				1	2		7	<1.0
AB		6																					6	<1.0
LL																			3		2	1	6	<1.0
MS			2			1	1	1	1														6	<1.0
NA				6																			6	<1.0
PR	1		5																				6	<1.0
GF																1			4				5	<1.0
HX		2				3																	5	<1.0
LT	1		4																				5	<1.0
PF	2		3																				5	<1.0
TF																				5			5	<1.0
AO	2	1	1																				4	<1.0
CS										1									1	1	1		4	<1.0
LX	1	1				1		1															4	<1.0
ST																			2		2		4	<1.0
AD	2							1															3	<1.0
AP																					1	2	3	<1.0
DX																			3				3	<1.0
TL																			2		1		3	<1.0
CA								1	1														2	<1.0
EL													1			1							2	<1.0
GG																			2				2	<1.0
GM																			1			1	2	<1.0

(continued)

TABLE 23. (continued).

	Headwaters			Upper River				Middle River		Lower River				Upper Estuary				Middle Estuary	Lower Estuary					%
	R	D	L	R	F	D	L	R	D	R	F	D	L	R	F	D	L	L	R	F	D	L	TOTAL	TOTAL
HE			1																1				2	<1.0
HP																				1	1		2	<1.0
MX							2																2	<1.0
PD																					1	1	2	<1.0
PY																					1	1	2	<1.0
RC																			2				2	<1.0
TR	2																						2	<1.0
TJ							2																2	<1.0
CJ															1								1	<1.0
CL																			1				1	<1.0
CZ								1															1	<1.0
EA																						1	1	<1.0
HL	1																						1	<1.0
HT							1																1	<1.0
HO												1											1	<1.0
KN																					1		1	<1.0
ME							1																1	<1.0
PT																			1				1	<1.0
PL					1																		1	<1.0
PA																	1						1	<1.0
SH													1										1	<1.0
SS																				1			1	<1.0
SL																				1			1	<1.0
SY		1																					1	<1.0
SD													1										1	<1.0
TG								1															1	<1.0
TH					1																		1	<1.0
TM																						1	1	<1.0
UC																						1	1	<1.0
VC																				1			1	<1.0
TOTAL	94	117	97	441	14	196	116	14	93	21	96	16	326	82	180	210	162	31	1,231	455	1,397	1,538	6,927	

Galeoides decadactylus, Schilbe mystus, Ethmalosa fimbriata, Ilisha africana, Pellonula vorax, Sardinella maderensis, and Arius latiscutatus.

Some species, especially YOY fish, which were not vulnerable to the standard series gill nets were more susceptible to trawls and seines. These species included: Hemigrammopetersius septentrionalis, Pseudotolithus senegalensis, Pentanemus quinquarius, Brycinus longipinnis, Pteroscion peli, Liza falcipinnis, Barilius senegalensis, Brachydeuterus auritus, and Tilapia spp.

Non-standard series fishing also captured some fish species that were not taken during standard series fishing. These species included: Carcharhinus limbatus, Clarius anguillaris, Clarius lazera, Ephippion guttifer, Galeorhinus galeus, Gymnura micrura, Hyporhamphus picarti, Kribia nana, Mormyrops deliciosus, Nannocharax ansorgei, Pisodonphis semicinctus, Pteroscion peli, Rhinobatos cemiculus, Synaptura lusitanica, Synodontis annectens, Tilapia galilaea, Trichiurus lepturus, Umbrina cirrosa, and Vanstraelenia chirophthalmus.

Fonticulus elongatus and Ilisha africana comprised almost half (47%) of the total non-standard series catch (Table 23). Neither of these species were collected in fresh water. Pellonula vorax was caught in all zones except the middle and lower estuaries. Hemigrammopetersius septentrionalis was captured exclusively in fresh water. An additional 17 fish species comprised more than 1% of the total non-standard series fish catch. Seven of the 10 most abundant fish caught in non-standard series samples were also included in the major species grouping for the standard series fish catch. Of the species caught in both standard series and non-standard series samples, catch statistics from one sampling scheme generally agreed with those of the other scheme in terms

of spatial and temporal distribution. This was particularly true for major fish species which occurred in abundance in catches from both types of sampling. We interpreted the similarity in species catch between the two types of sampling to reflect the generally widespread abundance and distribution of the major species, because the variety of gear used to capture these fish reduced the selectivity of our fishing methods.

The following catch distribution by zone occurred for non-standard series sampling (sampling effort, summarized in Appendix 2, is shown parenthetically): headwaters zone - 4.4% (3%); upper river zone - 11.1% (24%); middle river zone - 1.5% (5.2%); lower river zone - 6.6% (8%); upper estuary zone - 9.2% (15%); middle estuary zone - <1% (<1%); lower estuary zone - 66.7% (48%). The fish catches in the headwaters zone, lower river zone, and middle estuary zone were proportional to the sampling effort. In the upper river zone, middle river zone, and upper estuary zone, the fish catch was proportionately lower than the sampling effort. Only the lower estuary zone showed a fish catch that was proportionately larger than the fishing effort. This suggests that the abundance of fish in the lower estuary was relatively higher in this zone in comparison with the other zones of the river. Also, excluding _Pellonula vorax_, _Hemigrammopetersius septentrionalis_, and _Brycinus longipinnis_ which are freshwater fish, the lower estuary zone non-standard series catch of the remaining 10 most abundant fish comprised about 69% of the total non-standard series catch.

The following catch distribution by period occurred for non-standard series sampling (sampling effort is shown parenthetically): rising water - 26.5% (43%); peak flood - 10.8% (19%); declining water - 29.3% (14%); and low water - 32.8% (24%). During the periods of rising water and peak flood, fish

catches were proportionately less than the sampling effort. During the periods of declining and low water, fish catches were proportionately greater than the sampling effort. This suggests that the density and/or activity of fish was higher during declining and low water than during rising water and peak flood.

In descending order the ranked abundance of the 13 major species caught in standard series sampling and the 13 most abundant species in non-standard series samples was:

Rank	Standard series sampling	Non-standard series sampling
1	*Sardinella maderensis*	*Fonticulus elongatus*
2	*Ethmalosa fimbriata*	*Ilisha africana*
3	*Pellonula vorax*	*Pellonula vorax*
4	*Hemigrammopetersius sepentrionalis*	*Hemigrammopetersius sepentrionalis*
5	*Schilbe mystus*	*Pseudotolithus senegalensis*
6	*Chrysythys nigrodigitatus*	*Pentanemus quinquarius*
7	*Fonticulus elongatus*	*Galeoides decadactylus*
8	*Ilisha africana*	*Sardinella maderensis*
9	*Arius latiscutatus*	*Brycinus longipinnis*
10	*Synodontis gambiensis*	*Ethmalosa fimbriata*
11	*Brycinus nurse*	*Pteroscion peli*
12	*Arius heudeloti*	*Arius latiscutatus*
13	*Brycinus longipinnis*	*Liza falcipinnis*

Eight species of fish were caught in both sampling regimes. This represents a 69% overlap in species diversity among the top 13 species, although the absolute rank for a given species varied with the sampling regime. Four species of fish, *Pseudotolithus senegalensis*, *Pentanemus quinquarius*, *Galeoides decadactylus*, and *Liza falcipinnis*, were included in the 13 most abundant fish taken in non-standard series samples but were not included in the standard series major species.

The differences in rank for the various species listed above were related to differences in gear selectivity. The major species collected in standard

series fishing were taken with experimental gill nets. The 13 most abundant species collected in non-standard series fishing were netted using a combination of gill nets, trawls, seines, and other gear. However, the three most abundant species for standard series and non-standard series sampling comprised 62% and 47% of the total catch, respectively, for each of the sampling regimes. The reason for this was that both adult and juvenile fish were abundant and occurred in several zones of the river, thereby expanding the vulnerability of these species to the spectrum of fishing gear deployed.

LARVAL FISH

INTRODUCTION

Sampling Effort

Over the four sampling periods, 278 ichthyoplankton samples were collected during the study. Of these, 252 were standard series samples taken from the primary study sites and 26 were collected during supplemental or special (floodplain or bolon/mangrove) studies. Fewer samples were collected in the headwaters zone than in the other zones because of the reduced size and flow of the river. Eight samples were collected at the headwaters sampling site during declining and low water, and four were taken during rising water (Appendix 2). Samples were not collected at night or during rising water.

Approximately the same level of sampling effort was devoted to each of the four remaining zones. Adverse sampling conditions resulted in collection of fewer samples from the upper river and lower estuary during rising water than was originally planned (Appendix 2). Over the four field trips 53, 64, 64, and 63 larvae samples were taken, respectively, from the upper river, lower river, upper estuary, and lower estuary. Supplementary and special study samples included four samples collected from Kekreti, 20 samples from the bolon, and two samples from the flood plain. The bolon was sampled during all four cruises. Sampling was performed at Kekreti only during the declining water and in the floodplain only during peak flood.

Identification and Classification

Taxonomic studies on West African larval fish are scarce. Because of lack of published descriptions, most larval fish that were collected from the Gambia River were identified only to genus or family level, with the exception

of clupeid larvae. Larval fish identifications utilized taxonomic works of Aboussouan (1972a, 1972b, 1972c and 1975), Lippson and Moran (1974), and Miller et al. (1979). A list of characteristics of families of larval fish collected are included (Table 24). Members of the family Clupeidae were identified to species with the aid of publications of Bainbridge (1961), Dessier (1969), Albaret and Gerlotto (1976), and Conand (1978). Larval fish mutilated beyond recognition were classified as damaged larvae. Information on spawning season of fish in The Gambia, data on gonad conditions of adult fish during larvae sampling, and occurrence of growth series of larvae were useful in the identification of fish larvae. Dr. Alain Aboussouan (Station Marine Endoume, Rue de la baaterie des Lions, 13007 Marseille, France) and Dr. Francois Conand (49 Quai Jongkind, 38,000 Grenoble, France) assisted us in the identification of several species and families of larval fish. Taxa of larval fish that we collected were classified by order and family, and whenever possible, genus and species (Table 25). Because of the absence of taxonomic keys for fish eggs, no attempt was made to identify fish eggs collected except for the eggs of *Ethmalosa fimbriata* which were described by Albaret and Gerlotto (1976).

General Distributions

Eighteen taxa (families or genera) of fish larvae and fry were collected in the Gambia River during 1983-1984 (Table 25). The headwaters was not sampled during rising water and peak flood. No larval fish were collected in this zone during declining and low water.

In the upper river no fish larvae were found during rising and declining water. Two taxa of larval fish (*Barbus* and Cyprinidae) were caught during

TABLE 24. Some characteristics of larval fish families collected in the Gambia River.

ELOPIDAE
- Leptocephalus larvae
- Myomeres ca. 75
- Pelvic fins present, caudal fin forked
- Dorsal and anal fins short-based, located near caudal fin

CLUPEIDAE
- Body long and slender
- Anus located far behind mid-point of body
- Preanal myomeres 26-40
- Vertebrae 42-46
- Yolk sac small, anterior
- Yolk-sac larvae lightly pigmented

CYPRINIDAE
- Yolk sac anteriorly spherical and posteriorly cylindrical on most species
- Anus located at a point 50 to 65% of the body from snout
- Air bladder obvious
- Preanal myomeres 19-30
- No oil globule in yolk sac
- Dorso-lateral, mid-lateral, ventral, and mid-ventral rows of pigment usually present

BAGRIDAE
- Young hatched as juvenile
- 3 or 4 pairs of barbels
- Nasal opening well separated
- Spine on dorsal and pectoral fins
- Branchiostegal membranes free or attached

BLENNIDAE
- Short, stubby yolk-sac larvae
- Vent well anterior, in thoracic region
- Pectoral fins large, anal fin long
- Spinous and soft dorsal fins long and continuous
- Well-defined preopercular spines
- 35-38 myomeres

CARANGIDAE
- Gut straight, bent near anus
- Finfold wide in early larval stage
- Preopercle with short, median spine
- Total myomeres 26, vertebrae 24-26
- Preanal length 50-55% of standard length
- Pigment on ventral and dorsal sides and on margin of finfold

(continued)

TABLE 24. Continued.

GOBIIDAE	
	Anus near mid-point of body
	Large gas bladder with pigment dorsally
	First dorsal fin develops much later than other vertical fins
	Myomeres 25 or 26, vertebrae 26
	Light pigmentation
MUGILIDAE	
	Body robust, mouth large
	Anus located behind mid-point of body
	First dorsal fin 3-5 spines
	Distinct rows of pigment above gut and along mid-lateral line
MULLIDAE	
	Gut short, no spines on head
	Myomeres 24; 5 + 19 at 3.5 mm, 10 + 14 at 7 mm
	Triangular melanophores on head
	Mid-lateral and mid-ventral rows of melanophores
POLYNEMIDAE	
	Head and mouth large, body slender
	Anterior gut massive
	Finfold narrow in early larvae
	Anal papilla protruding
	Mouth gape reaching middle of eyes
	24 vertebrae
SCIAENIDAE	
	Vent well anterior to mid-point of body
	Head large, preopercular spines prominent
	Oil globule present
	24 or 25 vertebrae
SYNGNATHIDAE	
	Body very long, mouth small
	Bony ridge on head and body
	Bony ring around body
CYNOGLOSSIDAE	
	Anal opening on right side
	A few elongated dorsal fin rays in early larvae
	Head large, body slender
	Vertebrae 56-61
CYPRINODONTIDAE	
	Stubby, robust larvae
	Vent anterior, located at 2/5 of body from snout
	Caudal fin with rays at hatching
	Mouth superior

TABLE 25. Taxa of fish larvae and fish fry collected in the Gambia River during 1983-1984.

Order	Family	Genus and Species
Elopiformes	Elopidae	
Clupeiformes	Clupeidae	Ethmalosa fimbriata Ilisha africana Pellonula vorax Sardinella maderensis
Cypriniformes	Cyprinidae	Barbus Barilius
Siluriformes	Bagridae	Chrysichthys
Atheriniformes	Cyprinodontidae	Aplocheilichthys
Gasterosteiformes	Syngnathidae	
Perciformes	Blennidae Carangidae Gobiidae Mugilidae Mullidae Polynemidae Sciaenidae	
Pleuronectiformes	Cynoglossidae	

peak flood and one taxon (Pellonula) occurred during low water. The small numbers of species represented in our samples relative to species diversity of adult fish in the river indicated that many species of larval fish were able to avoid plankton nets, particularly those species that spawn in protected areas and could not be sampled effectively. High density of total larvae during peak flood (7,150 larvae/1,000 m^3) probably resulted from peak hatching of one species of cyprinid during sampling. Because of its strong current, the river was unsuitable as a spawning ground for most fish species during peak flood. Larval Cyprinidae that were collected probably hatched in quiet

waters and later drifted into the current. The density of larval fish (300 larvae/1,000 m^3) established through sampling in February-March during low water (Table 26) was relatively low compared with other stages of the river. Most larvae were 3-5 mm in September-October during peak flood (Fig. 20) and 3 mm during low water.

In the lower river, five larvae taxa (*Chrysichthys*, Albulidae, Gobiidae, Carangidae, and *Pellonula*) were collected during the four sampling periods. Albulidae and Carangidae were marine fish and probably did not spawn in freshwater habitats. Larvae that were sampled in the lower river were probably transported by tidal currents from brackish water to the lower river. The low number of larval species collected in this zone suggested that larvae of most species remained outside the main river channel. The density of total numbers of fish larvae in the lower river ranged from 1,404 larvae/1,000 m^3 during peak flood to 15,568 larvae/1,000 m^3 during low water (Table 26). Average density of total larvae in the lower river over the four cruises (9,587 larvae/1,000 m^3) was the highest of all zones. Because larval *Pellonula* comprised more than 90% of all larvae collected, variations of total larvae densities in the lower river during the four flood stages resulted mainly from changes of spawning intensity of this taxon. Larvae collected ranged from 1.5 to 25 mm (Fig. 21), with a mode of 3-5 mm.

In the upper estuary six larvae taxa (Carangidae, *Ethmalosa*, Gobiidae, *Pellonula*, Sciaenidae, and Syngnathidae) were collected during the study. These catches indicated that both marine and freshwater fish utilized the upper estuary for spawning and nursery grounds. The total number of species collected was low relative to other river zones and appeared to change very little with changes in salinity. During rising water and low water when

TABLE 26. Density (number/1,000 m^3) of total fish larvae (all taxa combined) collected in each zone of the Gambia River during 1983-1984. River stage: rising water = Jul-Aug 1983, peak flood = Sept-Oct 1983, declining water = Dec 1983, low water = Feb-Mar 1984.

Cruises Zones	Jul-Aug 1983	Sept-Oct 1983	Dec 1983	Feb-Mar 1984	Total	Average
Headwaters	-	-	0	0	0	
Upper River	0	7,150	0	300	7,450	
Lower River	7,322	1,404	14,056	15,568	38,350	9,587
Upper Estuary	678	2,404	17,287	2,168	22,537	5,636
Lower Estuary	2,858	1,034	373	1,679	5,944	1,486
Total	10,858	12,096	35,116	20,315		
Average	3,619	3,028	8,779			

salinity was 13.15 ppt and 11.08 ppt, respectively, five taxa of larval fish were collected. Four taxa were represented in samples collected during peak flood and declining water when salinity decreased to 0.23 ppt and 2.15 ppt, respectively. The density of total numbers of fish larvae ranged from 678 larvae/1,000 m^3 during rising water to 17,287 larvae/1,000 m^3 during declining water. As was observed in the lower river, total larval fish density in the upper estuary was influenced mainly by spawning of Pellonula. Average density of total numbers of fish larvae over the four cruises (5,636 larvae/1,000 m^3) was substantially lower than that of the lower river. Larvae were 2 to 25 mm. Small larvae, 2.5-5 mm were the dominant group (Fig. 22). Larvae 5-12 mm were more common in the upper estuary than in the lower river.

Two taxa of larval fish (Gobiidae and Pellonula) occurred in the bolon in the upper estuary. Densities of larval fish sampled in the bolon were usually lower than those sampled in the main river channel. During rising and declining water total larval fish density in the bolon was 1,000 larvae/1,000 m^3 and 2,000 larvae/1,000 m^3, respectively. Decreased larval abundance was noted

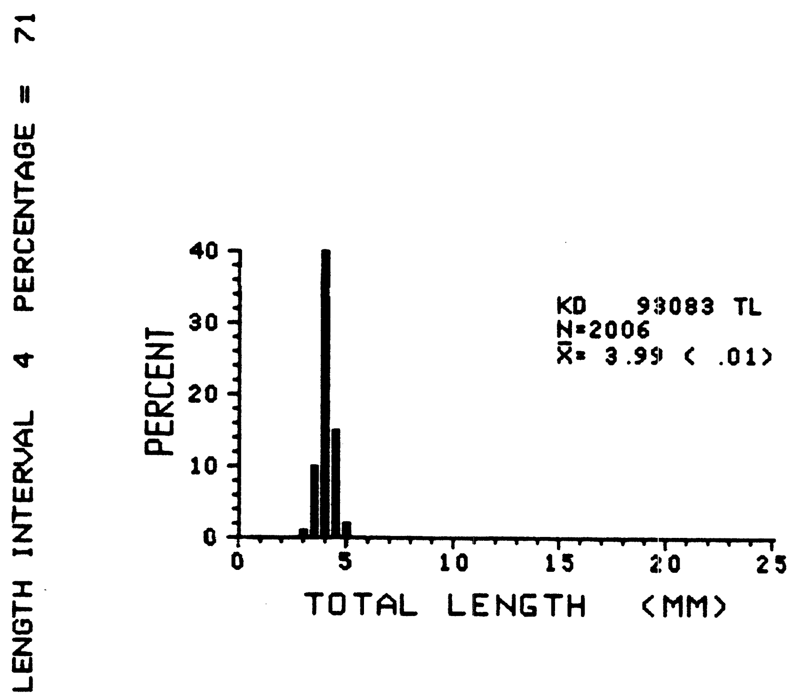


FIG. 20. Length-frequency histograms of total larval fish (all taxa combined) collected in the upper river study area, Gambia River, during September 1983, KD = Kedougou, TL = total larvae, N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

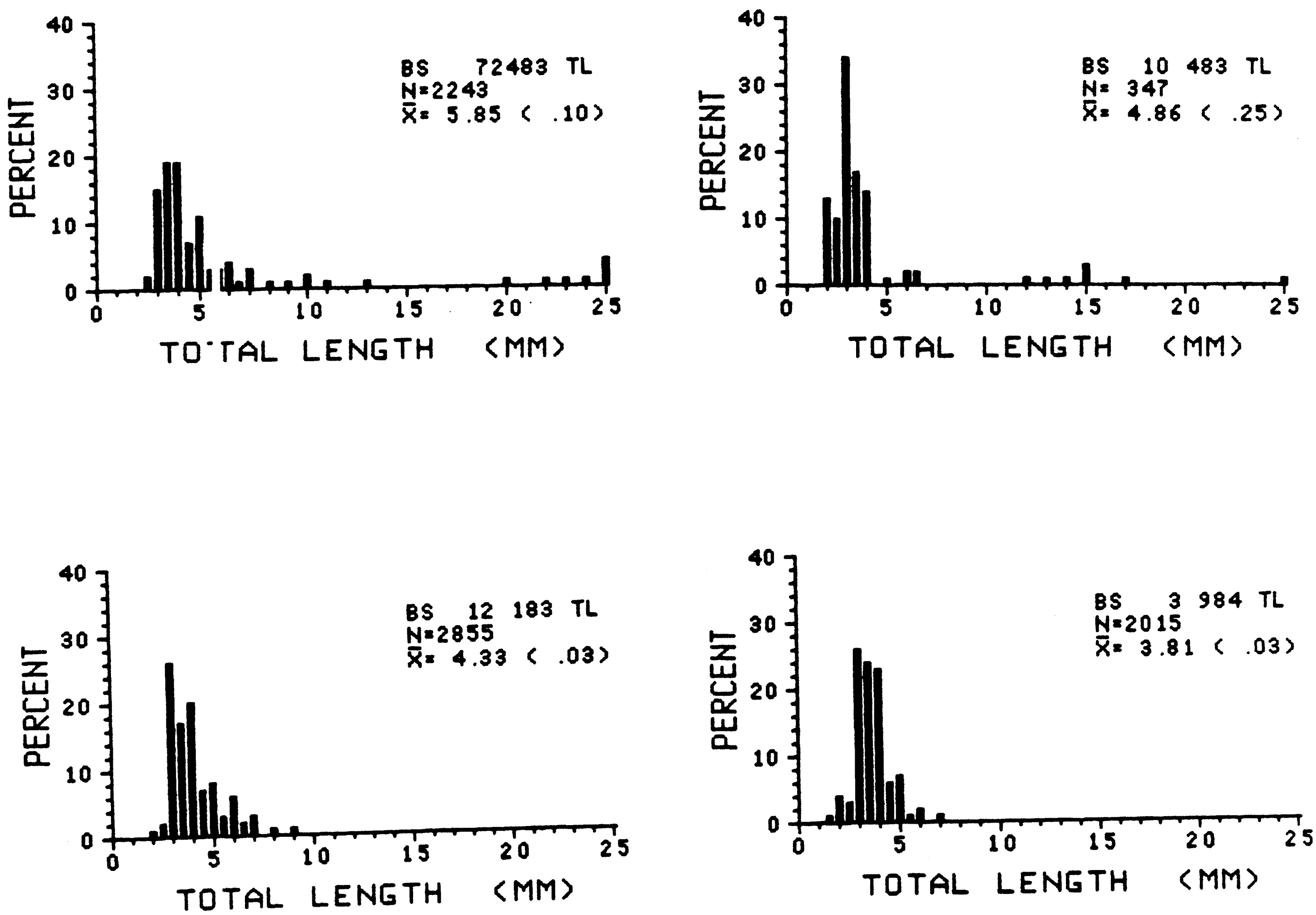


FIG. 21. Length-frequency histograms of total larval fish collected in the lower river study area, Gambia River, during 1983-1984. BS = Bansang, TL = total larvae, N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

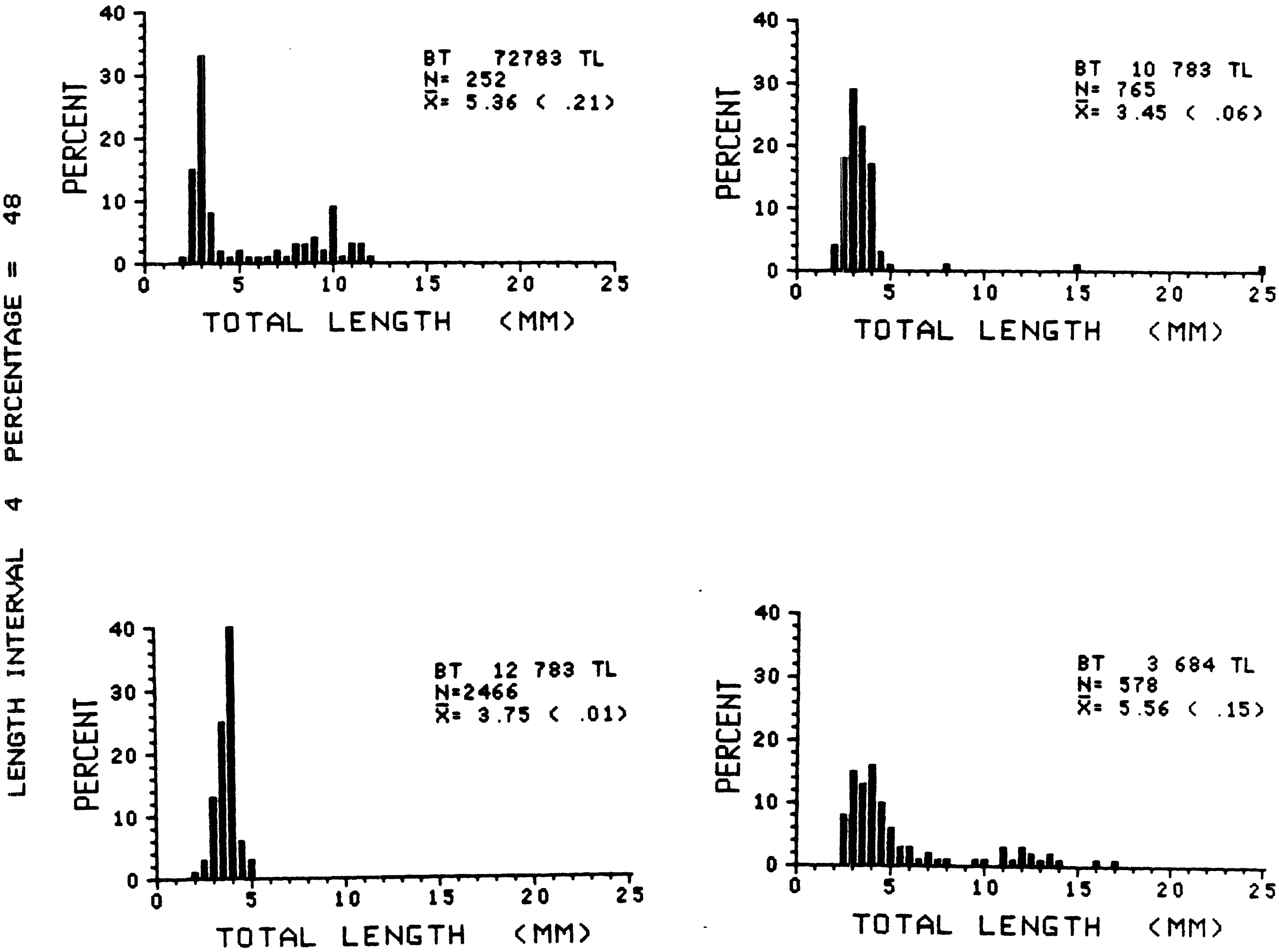


FIG. 22. Length-frequency histograms of total larval fish collected in the upper estuary study area, Gambia River, during 1983-1984. BT = Bai Tenda, TL = total larvae, N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

during peak flood and low water. No fish larvae were collected in the floodplain in the upper estuary. Because this area was flooded only during high tide and exposed to air during other phases of the tide cycle, little or no fish spawning took place there. A few fish larvae may have entered the floodplain during flooding at high tide. Larval fish collected in the bolon were 2-5 mm.

The taxonomic diversity of larval fish populations was highest in the lower estuary where 13 taxa were represented in samples collected (Table 27). Several larval fish taxa were recorded in the upper and lower estuaries including: Albulidae, Carangidae, Ethmalosa, Gobiidae, Sciaenidae, and Syngnathidae. A few other taxa of euryhaline fish larvae (Cynoglossidae, Ilisha, Mugilidae, and Polynemidae) were confined to the lower estuary. The remaining taxa of larvae recorded in the lower river (Blennidae, Sardinella, and Mullidae) were primarily marine species. Total larval fish density in the lower estuary ranged from 373 larvae/1,000 m^3 to 2,858 larvae/1,000 m^3. Average density of total larvae (1,486 larvae/1,000 m^3) was lower than that found in the upper estuary or the lower river. Total larval fish density in the lower estuary was probably very high during the period we did collect samples (March-July). Peak spawning of most fish occurred during that period. Larval fish in the lower estuary were 1.5-25 mm (Fig. 23). Larvae 1.5-2.5 mm were found in a higher proportion than in the upper estuary or lower river because of the abundance of early stages of Sciaenidae and Cynoglossidae larvae. Larvae of these species were small and poorly developed at hatching. Clupeid larvae, which dominated larval fish populations in the upper estuary and lower river, were generally longer than other larval fish during the early stages of development.

TABLE 27. Density (number/1,000 m^3) of each taxon on larval fish collected in each zone of the Gambia River during 1983-1984. River stage: rising water = Jul-Aug 1983, peak flood = Sept-Oct 1983, declining water = Dec 1983, low water = Feb-Mar 1984.

Cruises Zones	Jul-Aug 1983	Sept-Oct 1983	Dec 1983	Feb-Mar 1984
HEADWATERS	-	-	-	-
UPPER RIVER				
Pellonula vorax	0	0	0	300
Cyprinidae	0	7,143	0	0
Barbus	0	7	0	0
Aplocheilichthys	0	0	1	0
LOWER RIVER				
Elopidae	0	0	0	1
Carangidae	0	0	0	3
Chrysichthys	14	86	5	0
Gobiidae	62	207	503	189
Pellonula vorax	7,247	1,112	13,549	15,366
UPPER ESTUARY				
Elopidae	1	0	0	0
Carangidae	0	0	0	6
Clupeidae	3	0	0	0
Ethmalosa fimbriata	84	0	0	445
Gobiidae	442	470	1,138	1,138
Pellonula vorax	130	1,931	16,141	580
Sciaenidae	0	2	0	0
Syngnathidae	14	0	0	0
LOWER ESTUARY				
Elopidae	1			
Blennidae	5	52	6	8
Carangidae	6	34	0	3
Cynoglossidae	445	13	0	530
Ethmalosa fimbriata	45	14	74	579
Gobiidae	384	446	285	507
Ilisha africana	145	13	0	0
Mugilidae	128	17	3	39
Mullidae	6	11	4	0
Sardinella maderensis	73	324	0	0
Sciaenidae	1,118	105	0	0
Syngnathidae	0	3	0	9
Polynemidae	0	0	2	2
Damaged larvae	0	2	0	0

LENGTH INTERVAL 2 PERCENTAGE = 44

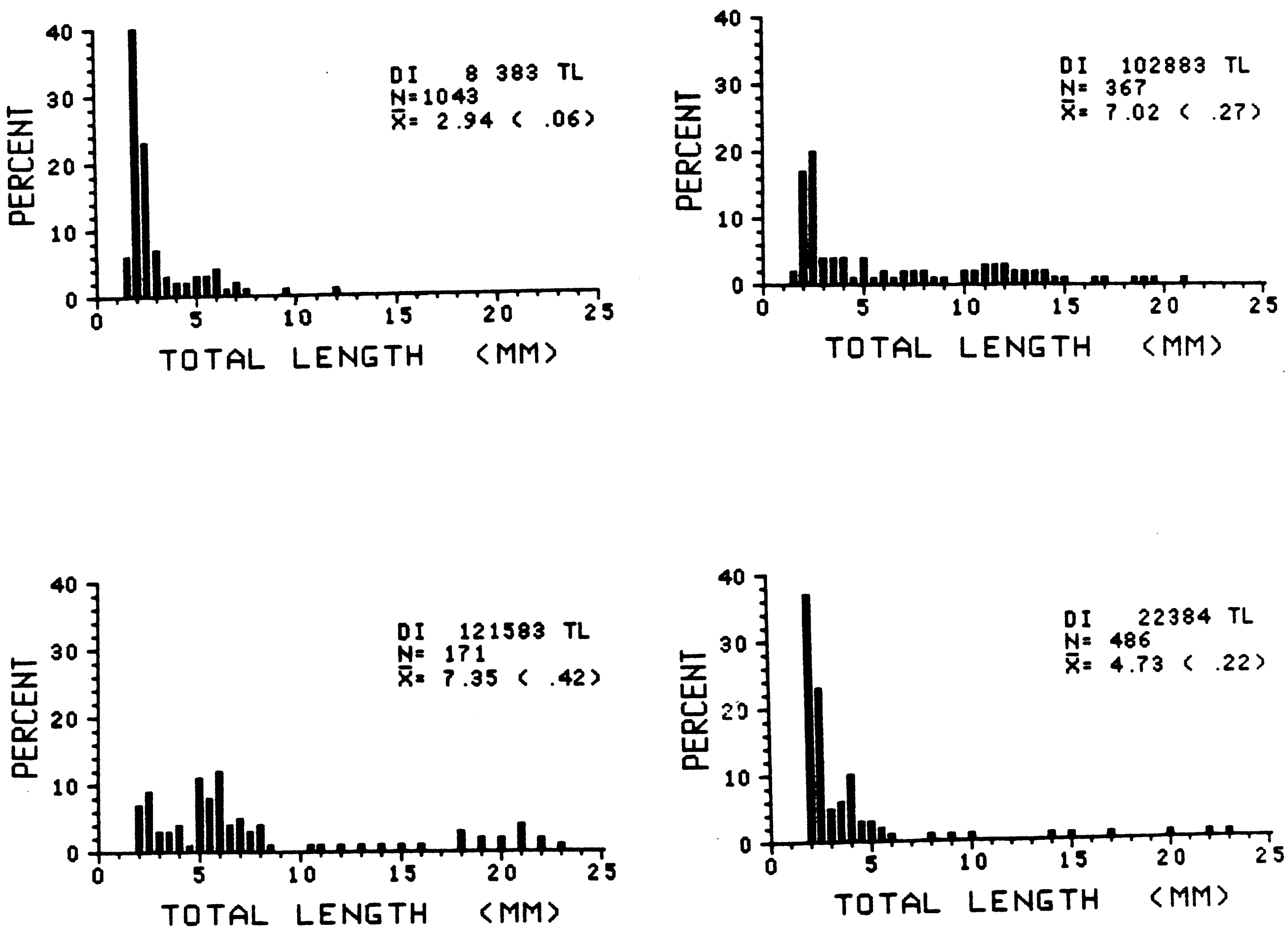


FIG. 23. Length-frequency histograms of total larval fish collected in the lower estuary study area, Gambia River, during 1983-1984. DI = Dog Island, TL = total larvae, N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

The number of taxa represented in our samples varied substantially over the four cruises. During rising water and peak flood, 13 and 16 species, respectively, were found in all zones. Only eight species were recorded during declining water and nine species during low water. This decrease of number of species occurred in the lower estuary (Table 27). These data indicated that more marine fish spawned during rising water and peak flood than during declining and low water.

In the upper estuary larval fish most affected by changes of salinity were Pellonula, which inhabited water relatively fresh or with very low salinity, and Ethmalosa, which preferred higher salinity. During periods of high salinity (rising and low water) five taxa of fish larvae were recorded in the upper estuary; three taxa were recorded during the low salinity period. Little change in the composition of larval fish taxa occurred during the four flood stages in the lower river.

Larval fish populations in the river were generally abundant during the four cruises. Mean density of total larvae in the river were similar during rising water (3,619 larvae/1,000 m^3) and peak flood (3,028 larvae/1,000 m^3). Higher mean density of total larvae was observed during declining water (6,779 larvae/1,000 m^3) and low water (5,103 larvae/1,000 m^3). Variations of larval fish abundance over the four cruises were due mainly to seasonal variations in abundance of Pellonula.

Pellonula larvae were by far the most abundant larval fish collected in the Gambia River (Table 27). Mean density of larval Pellonula in the lower river (9,318 larvae/1,000 m^3) was highest of any larvae taxon. Pellonula larvae had a wide geographical distribution, and were found in the upper river,

lower river, and upper estuary. They occurred the whole year around in the latter two zones.

Mean density of cyprinid larvae in the upper river over the four cruises (1,786 larvae/1,000 m^3) was high relative to other taxa. This taxon, however, did not appear to be one of the dominant larval fish of the Gambia River. Cyprinid larvae occurred only in the upper river and only during peak flood. Their high abundance resulted from a peak hatching during the sampling period.

Gobid larvae comprised one of the most abundant larval fish taxa and were widely distributed in the Gambia River. Larval gobies occurred in three zones (lower river, upper estuary, and lower estuary) and were found during all cruises in each zone. In contrast to *Pellonula* larvae, however, gobid larvae never reached great abundance in any zone, during any cruise. Highest mean density of gobid larvae (797 larvae/1,000 m^3) occurred in the upper estuary.

Larval Sciaenidae, Cynoglossidae, and *Ethmalosa fimbriata* were common in the Gambia River; their average densities in the lower estuary were 306 larvae/1,000 m^3, 247 larvae/1,000 m^3, and 178 larvae/1,000 m^3, respectively. Because no larva fish sampling was conducted during the peak spawning of these taxa, abundance of their larvae may be underestimated. All three taxa are estuarine fish. *Ethmalosa* occurred all year around in the lower estuary and during the dry season in the upper estuary.

Sardinella maderensis, Mugilidae, and *Ilisha africana* were common in the lower estuary, but probably spawned in the ocean. *Chrysichthys* were found in the lower river at an average density of 26 larvae/1,000 m^3. Adult and juvenile of this taxon were common in the lower river and upper estuary. Blennidae, Carangidae, Mullidae, Syngnathidae, and Polynemidae larvae were caught only occasionally during larval fish sampling.

TAXONOMIC ACCOUNTS

Clupeidae

Pellonula vorax --

Abundance and distribution -- *Pellonula vorax* is a small-sized clupeid fish distributed in West Africa, from the Senegal River to the Congo River (Daget and Iltis 1965). This species may be found both in freshwater and brackishwater habitats. It is an important link in the aquatic food chain, consuming zooplankton and serving as food for predatory fish (Johnels 1954). *Pellonula* larvae were found in the upper river, lower river, and upper estuary.

During declining and low water no larval *Pellonula* were collected in the headwater zone. This species may not be present in this zone. Daget (1960, 1962) did not find *Pellonula* during a survey of a portion of the Gambia River in the Fouta Djalon.

In the upper river, larval *Pellonula* were caught in densities from 475 larvae/1,000 m^3 to 951 larvae/1,000 m^3 during low water (Table 27). *Pellonula* larvae were found only in samples collected at night. The larvae probably remained near the bottom during dawn, day, and dusk. Larvae may also be able to avoid plankton nets during daylight. No *Pellonula* larvae were collected in the upper river during rising water, peak flood, and low water. Beach seining during rising water, however, captured numerous YOY *Pellonula* 20-30 mm, indicating that hatching of *Pellonula* larvae took place several weeks before the rising water sampling cruise (late June). Daget (1961) reported catching a 28-mm juvenile *Pellonula* in the Gambia River in the Niokolo Koba national park during April. These findings suggest that in the upper river spawning of Pellonula began in March and continued until the end of the dry season.

In the lower river Pellonula larvae were found during all four cruises (Table 27). These data agreed with findings of Johnels (1954) who pointed out the possibility of year-round spawning of Pellonula in the Gambia River. Abundance of Pellonula larvae, however, varied considerably over the four sampling cruises. Average larval density was lowest during peak flood (1,112 larvae/1,000 m^3). It increased dramatically during declining water (13,549 larvae/1,000 m^3) to reach a peak of 15,366 larvae/1,000 m^3 during low water. Larval fish density declined to 7,247 larvae/1,000 m^3 during rising water. ANOVA showed highly significant differences in density of larvae among the four cruises. Density during declining water was significantly higher than rising water density. There was, however, no significant difference in density of larvae between declining water and low water. These test results indicated that the significant difference between the four cruises was the result of low densities of larvae that occurred during rising water and peak flood. Abundance of larvae may be related to the supply of food. Zooplankton abundance in the river was lower during rising water and peak flood than during declining and low water. ANOVA showed no significant difference in density of larvae between nearshore and offshore sampling stations. Larval fish densities recorded during flood tide and ebb tide were not significantly different. Average densities of larvae at nearshore and offshore stations over the four cruises were 8,732 larvae/1,000 m^3 and 9,905 larvae/1,000 m^3, respectively. Average densities were 10,672 larvae/1,000 m^3 during ebb tide and 8,042 larvae/1,000 m^3 during flood tide. The above ANOVA results reflected the generally even distribution of Pellonula in the vicinity of the sampling site. In the lower river, while recently hatched larvae were abundant,

no fish eggs were collected in ichthyoplankton samples. Pellonula eggs probably attached to substrate immediately after spawning.

As was found in the lower river, Pellonula larvae exhibited considerable variation in abundance in the upper estuary (Table 27). Larvae were caught in low densities during rising water (130 larvae/1,000 m^3) and low water (580 larvae/1,000 m^3). Their abundance increased dramatically during peak flood (1,819 larvae/1,000 m^3) and declining water (16,140 larvae/1,000 m^3). Low abundance of Pellonula larvae in the upper estuary was probably related to high salinity. Salinity was respectively 13.25 ppt, 11.21 ppt, 0.23 ppt, and 2.15 ppt during rising water, low water, peak flood, and declining flood. ANOVA showed no significant density difference between the lower river and upper estuary, both during peak flood and declining water. These data indicated that Pellonula larvae had no preference for fresh water or brackish water (with salinities up to 2.15 ppt). The increase in larval fish abundance in the upper estuary between peak flood and declining water was, therefore, related to environmental factors other than salinity. Availability of food was probably the most important factor determining the abundance of larvae in the upper estuary during peak flood and declining water.

Length-frequency and growth -- In the upper river Pellonula larvae were generally small (3-4 mm). Large larvae may have avoided plankton nets which were sometimes towed more slowly in the upper river than in the lower river.

In the lower river Pellonula larvae ranged from 2.5 to 25 mm during each of the sampling cruises (Fig. 24). Larvae less than 4.5 mm usually comprised the major portion of the larval fish populations, whereas larvae 4.5 mm and larger were relatively scarce. In the lower river, where turbidity was

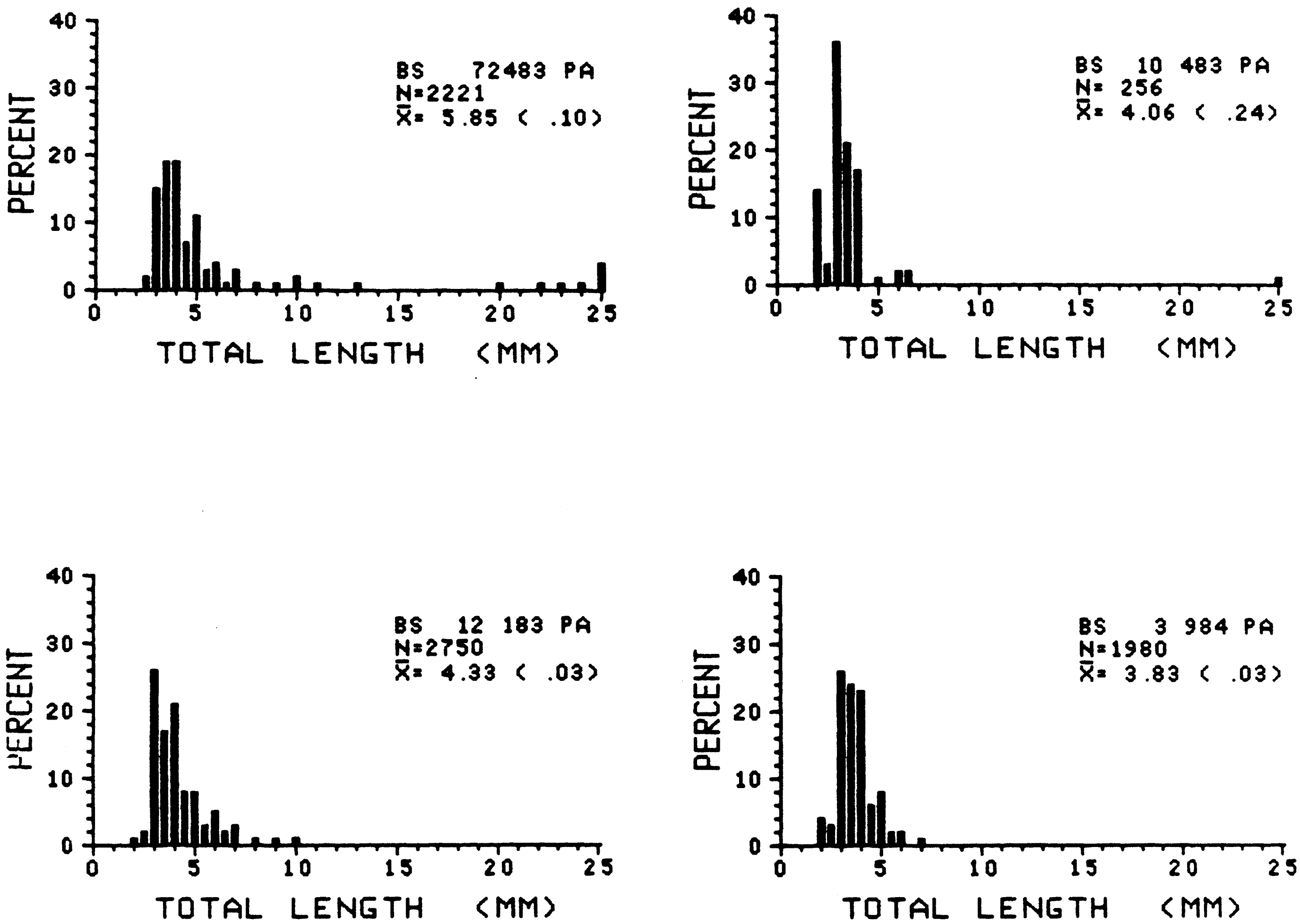


FIG. 24. Length-frequency histograms of Pellonula vorax larvae collected in the lower river study area, Gambia River, during 1983-1984. BS = Bansang, PA = Pellonula vorax, N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

usually high and larvae were probably unable to avoid plankton nets, lengths ranged from 2 to 10 mm. In this size range the decline of relative abundance of larvae, with increasing size, probably represented the mortality of larvae at various length intervals. The relative abundance of larvae decreased markedly at the 4.5-mm length interval and continued to decline with increasing size (Fig. 24). These data suggest that heavy larval mortality occurs at 4.5 mm. Because *Pellonula* larvae generally absorbed all their yolk at approximately 4 mm, this high mortality probably occurred during the critical stage of transfer from endogenous to exogenous feeding as has been observed for other larval fish species. Only a low percentage of larvae survived at 10 mm (Fig. 24). The generally low abundance of *Pellonula* in riverine habitat was noted by Daget and Durand (1981) and was suggested to be the result of high mortality of larvae. Insufficient food may be the main cause of mortality of larvae after yolk absorption.

Occurrence of newly hatched larvae (2-4 mm) during every cruise indicated that *Pellonula* spawned continuously in the lower river. Our samples suggested that size of *Pellonula* at hatching is about 2 mm. Larvae less than 3 mm were poorly represented in our samples. Growth of yolk-sac larvae may be determined by comparing the relative abundance of larvae 3, 3.5, and 4 mm in a series of samples collected on consecutive days. Among the three length-groups, 3-mm larvae were most abundant at 1600 hours on 9 March 1984 (Fig. 25). This dominant cohort attained 3.5 mm at 1,030 hours on 10 March and 4 mm at 2230 hours on 10 March (Fig. 25). These data indicated that yolk-sac larvae grew approximately 1 mm during 30 hours, corresponding to a rate of growth of approximately 0.8 mm/day. This value was comparable to the rate of growth of 0.9 mm/day reported for *Ethmalosa fimbriata* yolk-sac larvae (Albaret

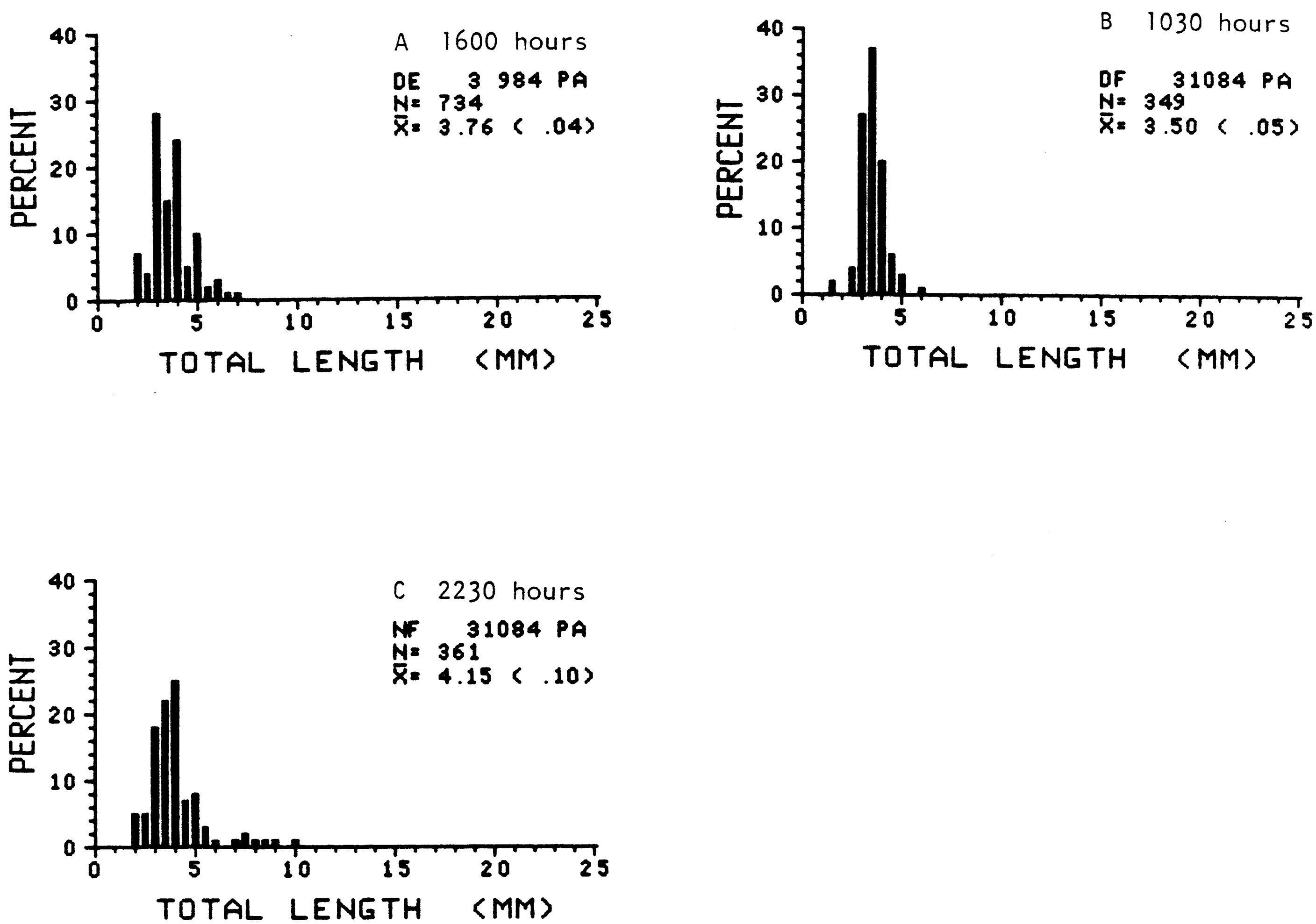


FIG. 25. Length-frequency histograms of Pellonula vorax larvae collected in the lower river study area, Gambia River, during 9-10 March 1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

and Gerlotto 1976). During the 30 hours, the 3-mm cohort suffered little mortality despite rapid growth of larvae (Fig. 25). These data supported our hypothesis that hatching of Pellonula larvae occurred continuously in the river.

In the upper estuary, Pellonula larvae ranged from 2 to 25 mm. Larvae less than 3 mm were scarce during all cruises. Length-frequency distribution of Pellonula larvae in the upper estuary was similar to that of the lower river. Larvae 3-4 mm were the most abundant group; heavy mortality occurred when larvae reached 4.5 mm. During rising water and low water only a small percentage of the newly hatched larvae were collected (Fig. 26). Spawning of Pellonula decreased when salinity was relatively high during these two cruises. Occurrence of a substantial number of larvae 5-25 mm suggested that survival rate of larvae increased during rising and low flood.

Early growth of Pellonula in the upper estuary may be estimated from relative abundance of larvae 3.5 and 4 mm. Samples collected at 1530 hours on 6 December 1983 were comprised of 3-mm larvae (5%), 3.5 mm larvae (27%), and 4-mm larvae (56%) (Fig. 27). On 7 December at 0400 hours the proportion of the 3-mm cohort decreased by 1% and the 3.5-mm cohort by 9%, while the 4-mm cohort increased by 10% (Fig. 27). These data indicated that the 3.5-mm larvae grew 0.5 mm during 13 hours. The growth rate of Pellonula in the upper estuary of 0.9 mm/day was comparable to the rate noted for larvae in the lower river. During the 13 hours there was no recruitment of larvae 3 and 3.5 mm and no decline in numbers of 4 mm larvae. At 2130 hours on 7 December, 16 hours later, numbers of 3.5 mm larvae increased substantially, while numbers of 4-mm larvae decreased by 14%.

LENGTH INTERVAL 4 PERCENTAGE = 52

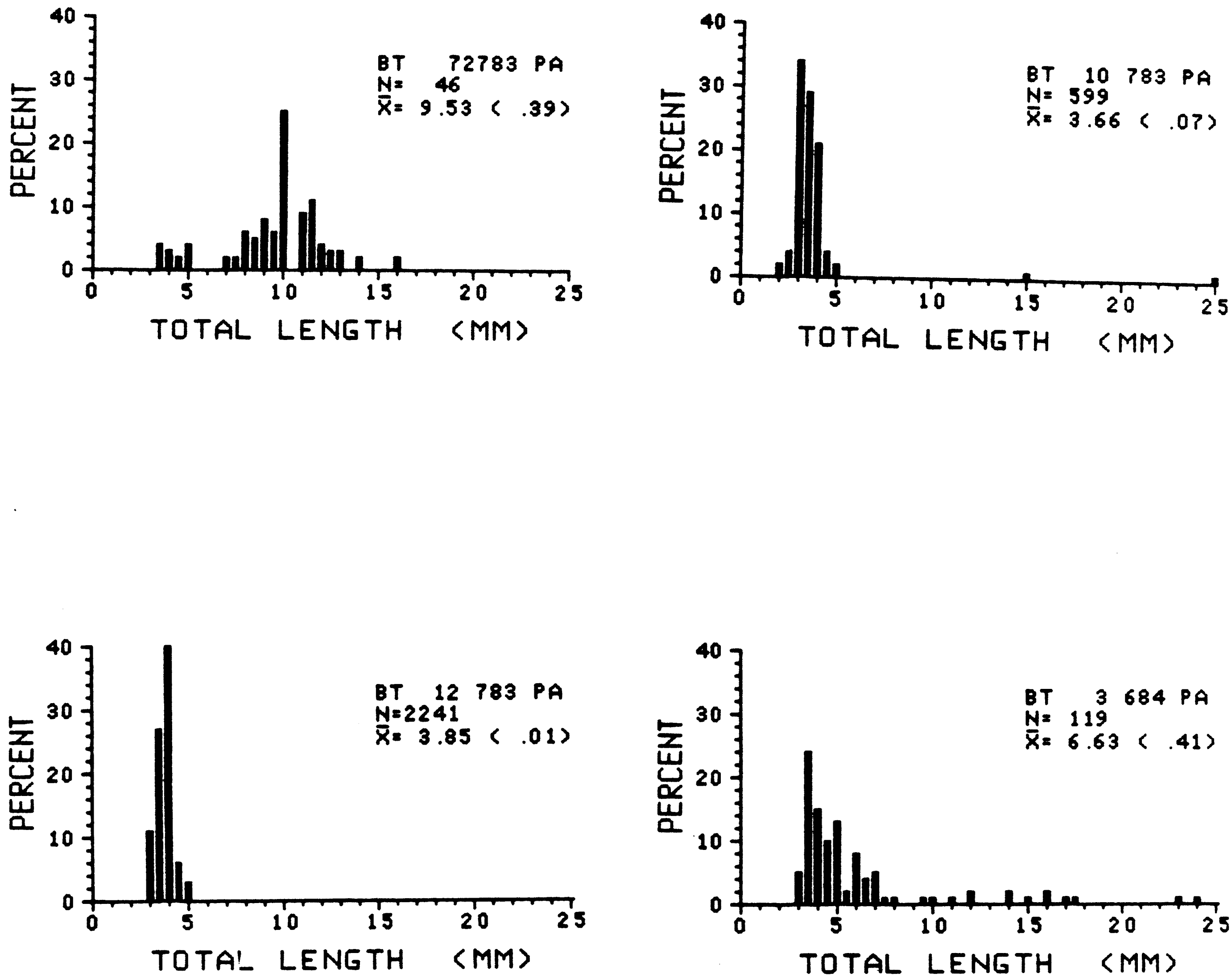


FIG. 26. Length-frequency histograms of Pellonula vorax larvae collected in the upper estuary study area, Gambia River, during 1983-1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

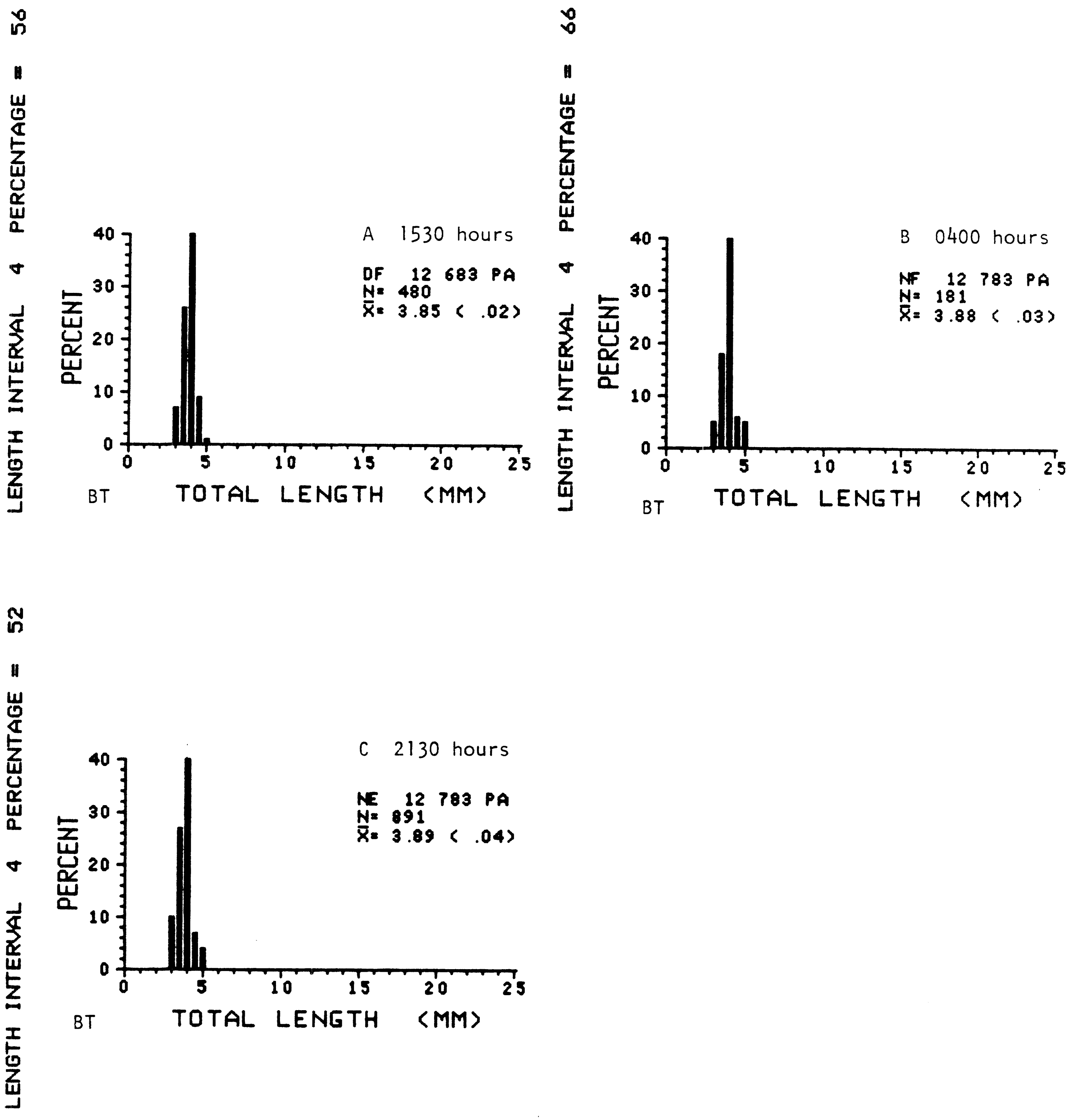


FIG. 27. Length-frequency histograms of Pellonula vorax larvae collected in the upper estuary study area, Gambia River, during 6-7 December 1983. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

Ecology -- The distribution and abundance of _Pellonula_ larvae may be influenced by several environmental factors. Data from the lower river indicated that _Pellonula_ spawned year-round in this zone. Absence of _Pellonula_ spawning in the upper river during rising water and peak flood may be due, in part, to strong currents and the high concentration of silt in the water.

Food supply was an important factor limiting the abundance of larvae. In the lower river low abundance of zooplankton during rising water and peak flood was probably the main cause of reduction of spawning of adults _Pellonula_. Johnels (1954) reported that larval _Pellonula_ occurred in great numbers during the rainy season. This high spawning activity may be related to the extensive flooding of floodplains. Because of low rainfall there was no flooding of low lands in 1983.

Salinity was an important factor affecting the abundance and distribution of _Pellonula_ larvae in the upper estuary. _Pellonula_ may spawn in brackish-water and freshwater habitats (Daget and Iltis 1965; Daget and Durand 1981). Our data indicated that _Pellonula_ larvae were abundant in salinity up to 2.15 ppt, but their populations were greatly reduced 13.27 ppt in salinity. Scheffers et al. (1972) reported the occurrence of larval _Pellonula_ in the Senegal River when salinity decreased to less than 10 ppt. These data suggested that little spawning of _Pellonula_ took place in water with salinity higher than 10 ppt. Larvae that appeared in waters of higher salinity may have been transported downstream by currents. Bainbridge (1961) noted that _Pellonula_ larvae found in the main estuary of the Sierra Leone River during the rainy season were probably swept downstream from surrounding creeks as a result of the increased runoff.

Water temperature in the 25-31°C range did not appear to affect the spawning of *Pellonula*. In the lower river substantial spawning was observed in water temperatures 30.8°C, 28.2°C, and 25.9°C. *Pellonula* larvae occurred in high abundance in 26.8°C water. In the upper river, the absence of *Pellonula* spawning during declining water may be, in part, the result of relatively low water temperature (23°C).

Impacts -- *Pellonula vorax* could become a dominant species in lakes created by the construction of dams across the Gambia River because of their abundance and capacity to spawn over a wide range of spatial and temporal conditions. Also, the high abundance of zooplankton that may develop under lacustrine conditions will increase the survival of *Pellonula* larvae and growth of *Pellonula* populations. Increases of *Pellonula* populations in man-made lakes have been observed in Lake Volta, Ghana (Freeman 1974; Daget and Durand 1981) and in Lake Kainji, Nigeria (Lewis 1974, Otobo 1974).

Ethmalosa fimbriata --

Distribution and abundance -- *Ethmalosa fimbriata* is a clupeid which inhabits the coastal and estuarine waters of West Africa from Mauritania to Angola (Charles-Dominique 1982). It is one of the most economically important species in the Gambia River Basin. *E. fimbriata* larvae were collected in the upper and lower estuaries of the river.

In the upper estuary, the highest density of *E. fimbriata* (445 larvae/1,000 m^3) occurred during low water at 24°C and 11.21 ppt salinity. Scheffers and Conand (1976) found a similar density (450 larvae/1,000 m^3) of *E. fimbriata* near Balingho during May in water at 28°C and 20 ppt salinity. In our

study, numerous *E. fimbriata* eggs were collected in samples taken from the upper estuary during low water, which indicated that spawning occurred during that sampling period. During rising water, a density of 45 larvae/1,000 m^3 was noted in water of 13.21 ppt salinity. No larvae were collected from the upper estuary during peak flood and declining water when salinities were 0.23 ppt and 2.15 ppt, respectively. These data indicate that spawning of *E. fimbriata* in the upper estuary probably ended during the period of rising water. Scheffers and Conand (1976) reported that *E. fimbriata* spawned near Balingho from February to July, reaching a peak in May. Densities of larval fish sampled in the upper estuary were generally low, perhaps because sampling was not conducted during the peak spawning period.

No *E. fimbriata* larvae were collected in the bolon near the upper estuary sampling site during rising or low water. *Ethmalosa*, which are pelagic spawners (Albaret and Gerlotto 1976), probably did not enter the bolon to spawn. In the lower estuary, *E. fimbriata* larvae were collected during all four cruises. Peak density of larval fish (579 larvae/1,000 m^3) occurred during low water at 23°C and 34 ppt salinity. Large numbers of eggs and numerous adults with gonads in ripe and ripe-running condition were collected in the lower estuary during low water. These data suggested that substantial spawning of *E. fimbriata* occurred in the lower estuary during February. Density of larval *Ethmalosa* in the lower estuary declined significantly from 45 larvae/1,000 m^3 during the period of rising water to 14 larvae/1,000 m^3 during peak flood. An increase in density (73 larvae/1,000 m^3) was noted during the period of declining water. Scheffers and Conand (1976) found that, in the ocean and lower estuary, *E. fimbriata* spawned all year with peaks occurring during March, June-July, and October-November. Our data indicated

that larval Ethmalosa were present in the lower estuary during the entire year, but populations of these larvae were generally small from August to December. No ripe adults were caught during the periods of rising water, peak flood, or declining water, which suggested that little spawning occurred in the sampling area during August-December. Larval Ethmalosa collected during this period may have drifted downstream from spawning areas above the sampling site. No samples were collected during the other peak-spawning months, June-July and March, as reported by Scheffers and Conand (1976).

Length-frequency distribution -- Larval *Ethmalosa fimbriata* collected during the low water period in the upper estuary ranged from 3.5 mm to 22 mm (Fig. 28). Albaret and Gerlotto (1976) reported that *Ethmalosa* hatched at 2.0 mm TL and grew to 4.0 mm during their first 48 hours. Based on this daily growth rate of about 1.0 mm, 3.5-4.5-mm larvae that appeared in our samples were probably 2-3 days old. If this growth rate was sustained after yolk absorption, the 7.5-14.0-mm cohort which comprised the bulk of samples was composed of larvae 1-2-weeks old. Scheffers et al. (1972) suggested that 10-20-mm *Ethmalosa* larvae were approximately 15 days old. Predominance of 7.5-14.0-mm larvae in our samples was probably the result of a peak hatch that occurred 1-2 weeks prior to our sampling efforts. Our observation of a continuous growth series among larvae collected demonstrated that the upper estuary was a suitable nursery area for *E. fimbriata*.

During rising water, *Ethmalosa* larvae collected in the upper estuary ranged from 7.5 mm to 19 mm. Absence of small (<7.5 mm) larvae indicated that no hatching occurred during the sampling period. Because no adult *Ethmalosa*

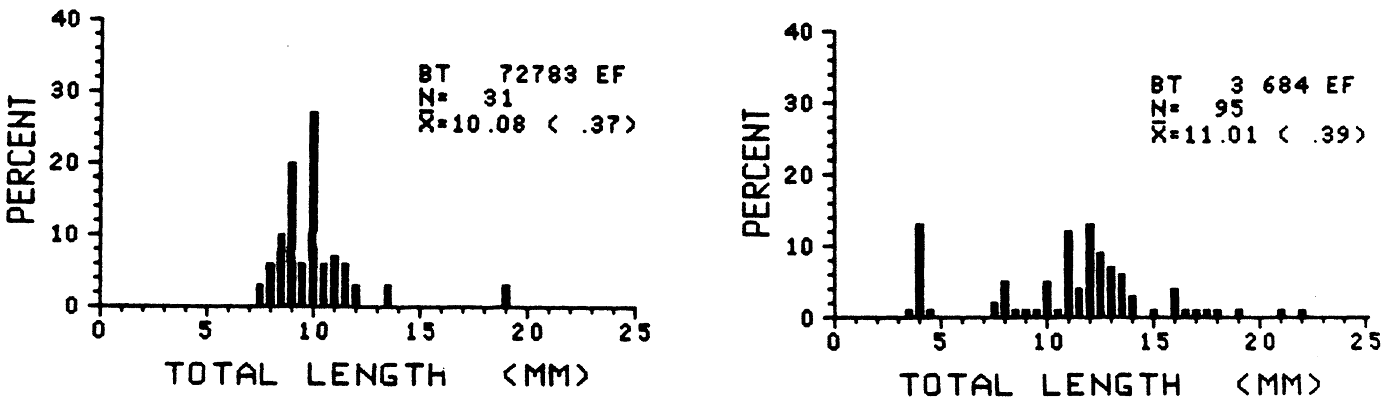


FIG. 28. Length-frequency histograms of Ethmalosa fimbriata larvae collected in the upper estuary study area, Gambia River, during July 1983 and March 1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

were collected in the upper estuary during this period, the larvae that were caught may have been transported upstream by currents.

In the lower estuary, Ethmalosa larvae ranged from 2.5 mm to 25 mm during low water (Fig. 29). As was found in the upper estuary, larvae collected in the lower estuary during low water showed a generally continuous growth series. Recently hatched larvae 2.5-6.0 mm were the most abundant cohort. Bainbridge (1961) reported that Ethmalosa larvae absorbed all their yolk by 4.0 mm. A substantial decline in relative abundance of Ethmalosa larger than 4.0 mm (Fig. 29) suggested that heavy mortality of larvae occurred after absorption of yolk was completed. Scarcity of 7-13-mm larvae probably reflected a period of reduced spawning prior to our sampling. Larvae 14-25 mm appeared in moderate numbers in our samples despite the ability of these large larvae to avoid plankton nets. Small larvae (2.5-5.0 mm) were present in low numbers during the periods of rising water, peak flood, and declining water (Fig. 29), thereby indicating a low rate of hatch during these three sampling periods.

Ecological relationships -- Salinity was an important factor limiting the distribution of adult Ethmalosa fimbriata in the upper estuary at certain times of the year. Adults migrated upstream to spawn in the estuary only during the period of maximum intrusion of salt water upriver, and returned to the lower estuary and ocean during the annual flood. This species has been reported to spawn in salinities ranging from 3.5 ppt to 38 ppt (Charles-Dominique 1982). Larvae were abundant in waters encompassing a wide range of salinities. In the Senegal River, immediately north of the Gambia River, larvae were most abundant in salinities of 5-10 ppt (Scheffers et al. 1972). In the Gambia River, Scheffers and Conand (1976) noted peak densities of

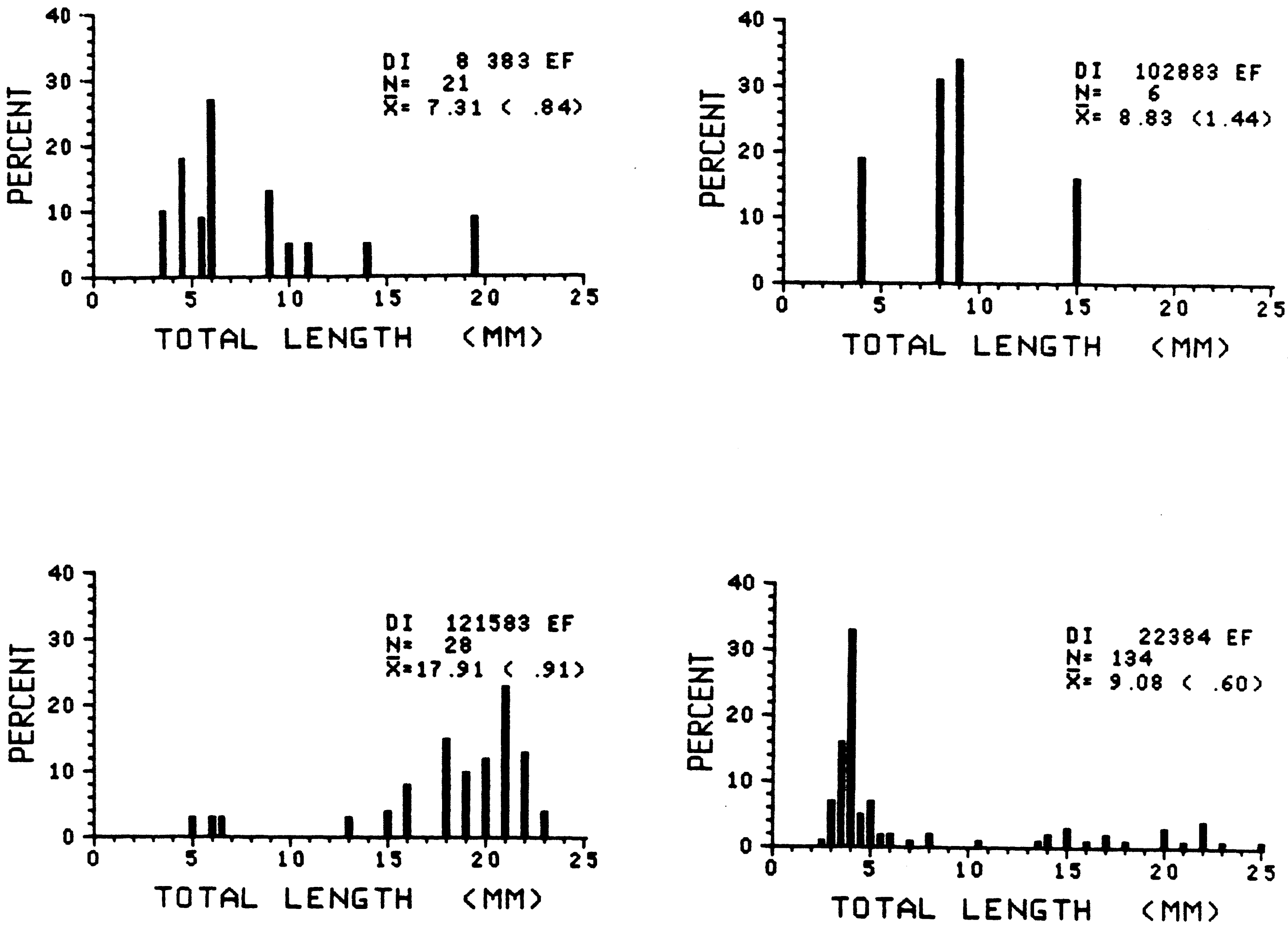


FIG. 29. Length-frequency histograms of Ethmalosa fimbriata larvae collected in the lower estuary study area, Gambia River, during 1983-1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

Ethmalosa larvae in 20 ppt salinity water. In our study, substantial numbers of larvae occurred in salinities of 11- 34 ppt.

Ethmalosa larvae occurred in 22-31°C water in the Senegal River (Scheffers et al. 1972). These authors believed that the range in temperature had no adverse effect (e.g., exclusion) on the distribution of larvae. In our study, large numbers of larvae were collected in the lower estuary in 23°C water. Scheffers et al. (1972) reported that at water temperatures less than 22°C *Ethmalosa* did not spawn in the Senegal River near Saint-Louis, Senegal.

Impacts -- Our study and that of Scheffers and Conand (1976) revealed that the Gambia River estuary above the proposed site of the Balingho barrage is an important spawning and nursery area for *Ethmalosa fimbriata*. The density of larvae in the upper estuary was approximately the same as that measured in the lower estuary. Therefore, construction of a barrage at Balingho and elimination of the estuarine portion of the river would result in elimination of *Ethmalosa* spawning and nursery grounds above the barrage site.

Sardinella maderensis --

Sardinella maderensis is a commercially valuable clupeid which is widely distributed in coastal waters of West Africa (Fischer et al. 1981). Larval *Sardinella maderensis* were caught in the lower estuary during rising water (August) and peak flood (October) in densities of 72 larvae/1,000 m^3 and 324 larvae/1,000 m^3, respectively. These data agree with those of Fagetti (1970) who reported that *Sardinella maderensis* spawned from June to October in coastal waters. Spawning was reported to take place at 10-50 m. Larvae that

we collected ranged from 5 mm to 23 mm (Fig. 30); most were more than 10 mm. Scarcity of newly hatched larvae in our samples suggested that little hatching took place in the estuary. Most *Sardinella* larvae caught in the lower estuary probably drifted in from offshore spawning areas. Fischer et al. (1981) reported that juvenile *Sardinella maderensis* sometimes entered the Gambia River estuary.

Ilisha africana --

Larval *Ilisha africana* were collected in the lower estuary during rising water and peak flood at densities of 144 larvae/1,000 m^3 and 13 larvae/1,000 m^3, respectively, No larval *I. africana* were caught during the periods of declining and low water. Scheffers and Conand (1976) found *I. africana* larvae in the upper estuary near Banjul from March to June and again during August and November. These data suggested that *I. africana* has a protracted spawning season in these waters. Larval *I. africana* collected during our study were 3.5-6.5 mm (Fig. 31). A few 26-mm juveniles were caught in the upper estuary during the peak flood.

Cyprinidae

Cyprinids are generally freshwater fish, and adults and juveniles of this family were common in the upper and lower river. Cyprinid larvae, however, were not found in the lower river. They occurred in great abundance (7,143 larvae/1,000 m^3) in the upper river during peak flood. Highest densities of larvae were measured at the beginning of the 2-day sampling period; larvae were relatively scarce by the end of the sampling period. These findings sug-

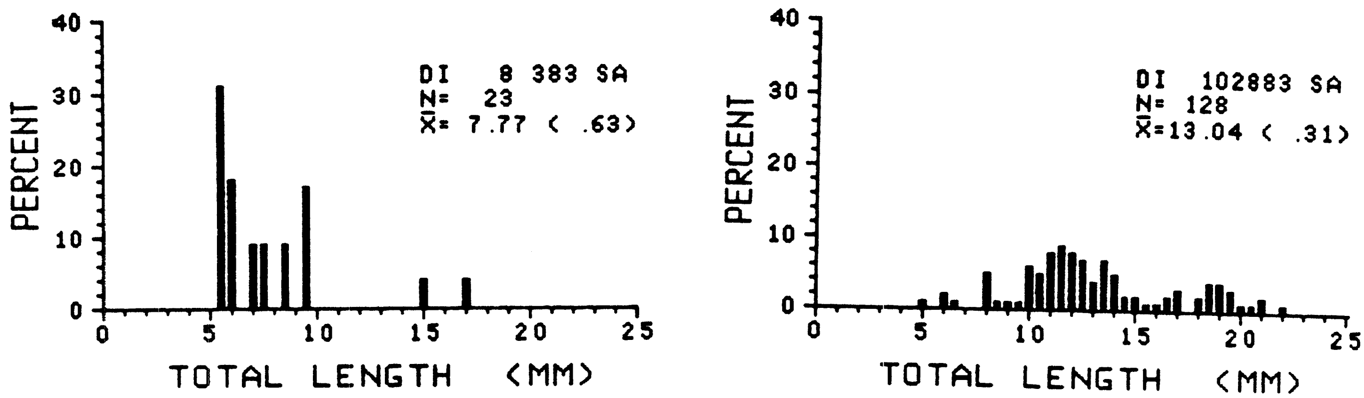


FIG. 30. Length-frequency histograms of larval <u>Sardinella maderensis</u> collected in the lower estuary study area, Gambia River, during August and October 1983. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

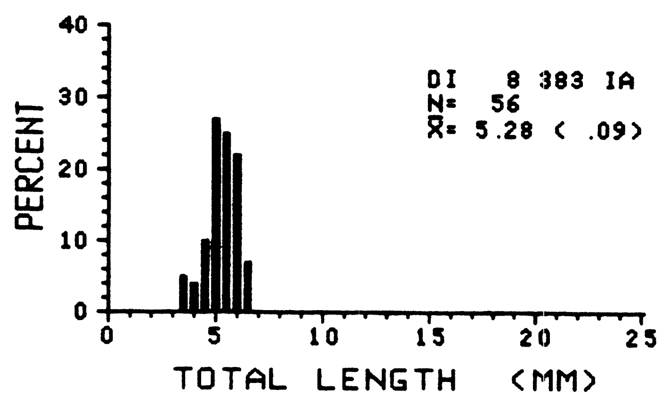


FIG. 31. Length-frequency histograms of larval <u>Ilisha africana</u> collected in the lower estuary study area, Gambia River, during August 1983. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

gest that our sampling coincided with a peak hatch of larvae upstream from the sampling site.

During peak flood, the upper river was probably not a suitable nursery ground for larval cyprinids as well as larvae of other fish. Currents in the main channel of the river were strong and turbulence was high as was turbidity. Zooplankton were less abundant than during other river stages. Cyprinid eggs probably adhered to rocks on the river bottom, but the larvae were entrained in the current shortly after hatching. It is possible that after hatching, the larvae are transported downstream to more suitable nursery areas, or they may mature during transport. Larvae collected during this study ranged from 2.0 mm to 5.0 mm (Fig. 32). No cyprinid larvae were collected during the periods of rising, declining, and low water.

Gobiidae

Gobies are demersal fish which are found in marine and fresh water (Fischer et al. 1981). In Senegambian waters, this family is represented by at least 19 species (Rainboth 1983). No species is currently of significant economic value. Larval gobiids were one of the most abundant taxa and occurred in samples collected in the lower river, upper estuary, and lower estuary.

In the lower river, larval gobies were found in low numbers (62 larvae/1,000 m^3) during rising water (Table 27). Densities of these larvae increased substantially during peak flood (207 larvae/1,000 m^3) and declining water (503 larvae/1,000 m^3). Densities declined to 189 larvae/1,000 m^3 during low water.

Larvae were most abundant in the upper estuary. Densities reached 442 larvae/1,000 m^3 during rising water, 470 larvae/1,000 m^3 during peak flood,

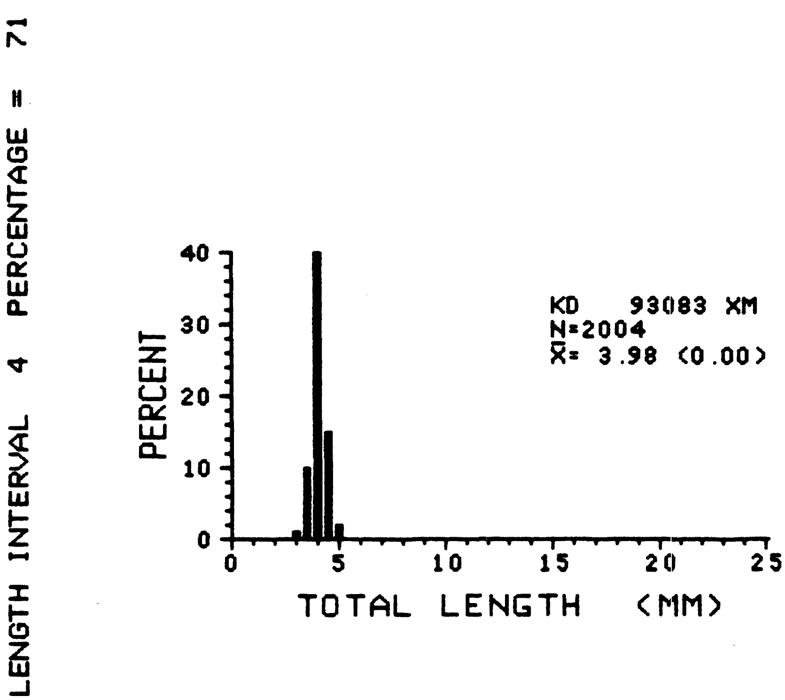


FIG. 32. Length-frequency histograms of larval Cyprinidae collected in the upper river study area, Gambia River, during September 1983. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

and 1,138 larvae/1,000 m^3 during declining water. These data indicate that spawning occurred year round, but peaked during declining and low water. Larval gobies were abundant during all periods in the upper-estuary bolon, which likely provided suitable spawning grounds for this group of fish.

In the lower estuary, larval gobies exhibited few fluctuations in abundance during the four river periods sampled. Densities ranged from 285 larvae/1,000 m^3 during declining water to 506 larvae/1,000 m^3 during low water.

In the lower river, larval gobies were generally small (1.5-3.5 mm) during rising water, peak flood, and low water (Fig. 33). Absence of large larvae suggests that either little growth occurred in the lower river during the 7-month span of the three sampling periods, or newly hatched larvae were rapidly transported downstream from the area. During declining water, however, larval gobies taken from the lower river were 1.5-8 mm, which indicates that this group of larvae did utilize the lower river as a nursery area. It is possible that larvae collected during declining water were a different species from those collected during rising water, peak flood, and low water. Identification to taxa lower than family was beyond the scope of the study.

In the upper estuary, larval gobies ranged from 2.0 mm to 13.5 mm, the majority being 2.0-3.5 mm (Fig. 34). Larvae larger than 7.5 mm were scarce in our samples, probably the result of gear avoidance. In the lower estuary, larvae ranged from 1.5 mm to 15.0 mm. Small larvae 1.5-3.5 mm were most abundant (Fig. 35). Larvae 5.0-8.0 mm were more abundant in the lower estuary than in the upper estuary. These data suggest that the lower estuary, like the upper estuary, was a suitable spawning and nursery area for some Gobiidae.

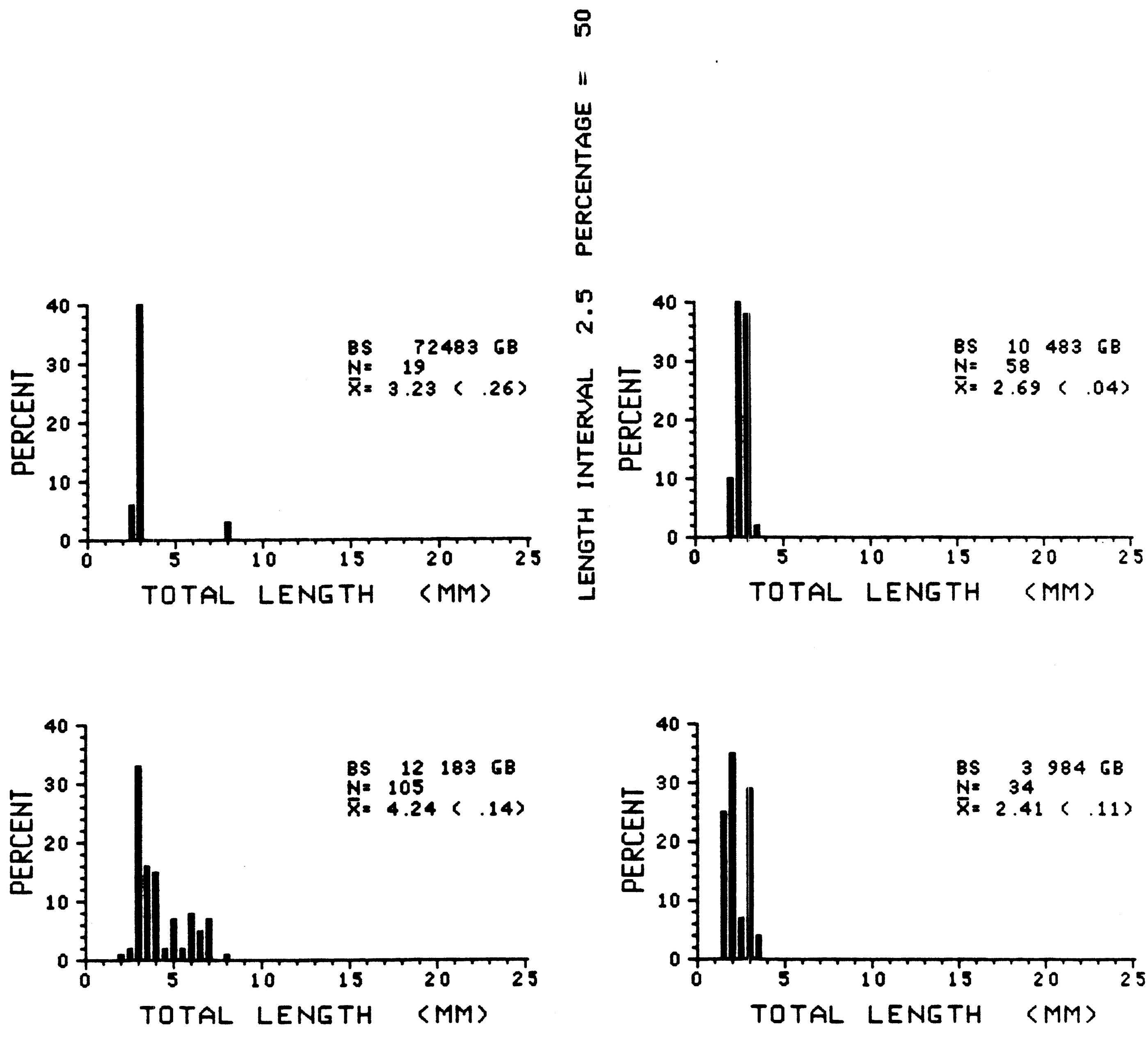


FIG. 33. Length-frequency histograms of larval Gobiidae collected in the lower river study area, Gambia River, during 1983-1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

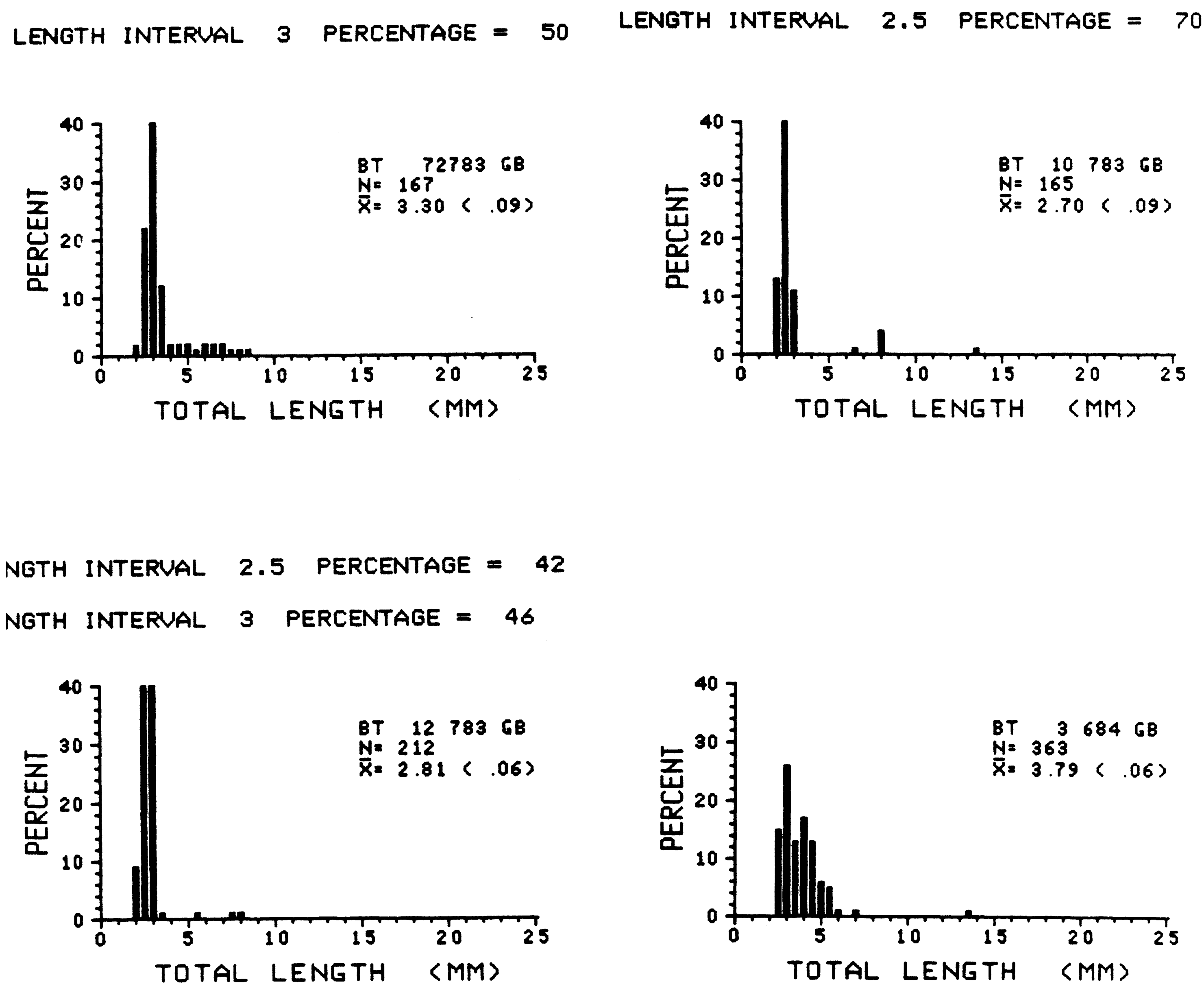


FIG. 34. Length-frequency histograms of larval Gobiidae collected in the upper estuary study area, Gambia River, during 1983-1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

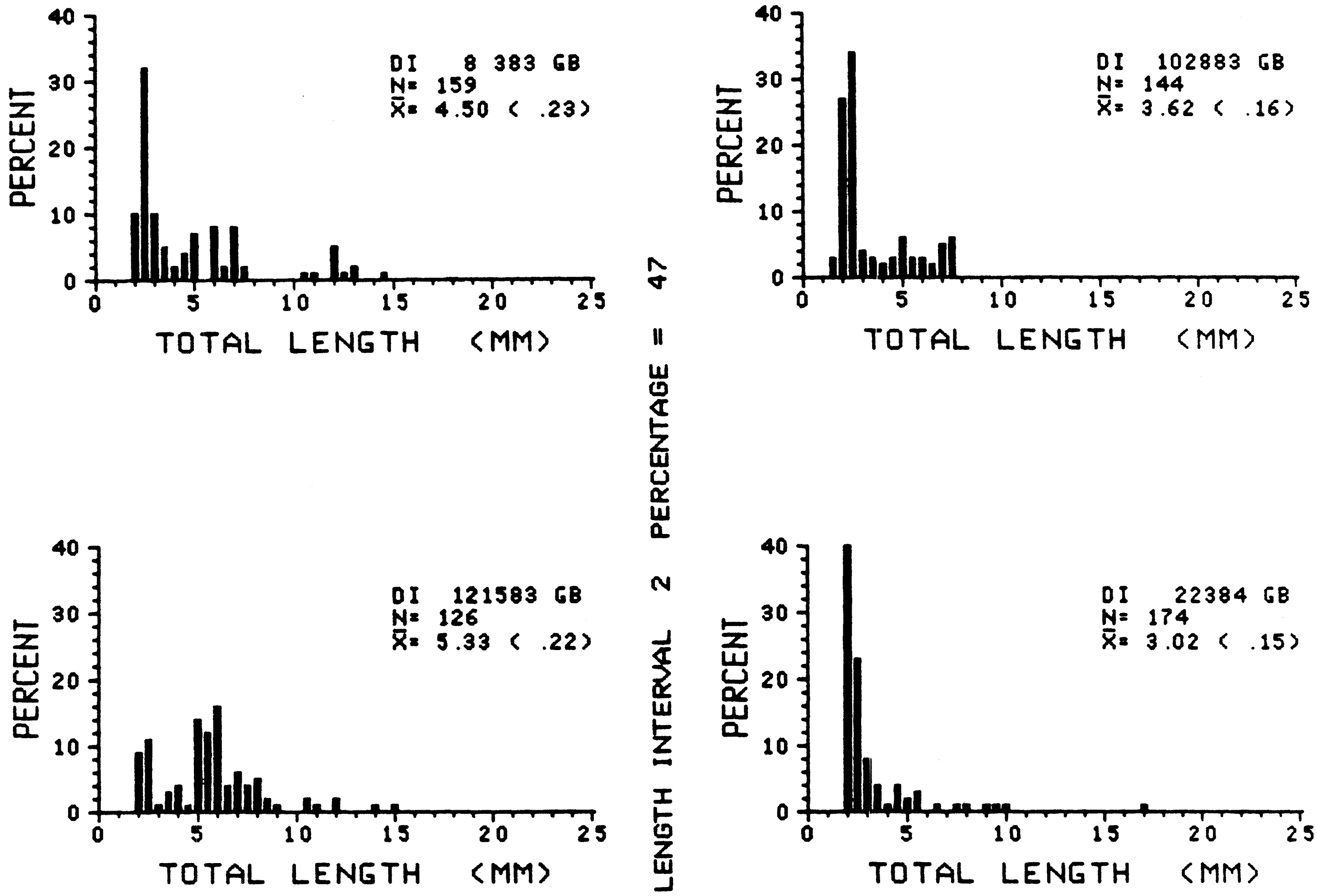


FIG. 35. Length-frequency histograms of larval Gobiidae collected in the lower estuary study area, Gambia River, during 1983-1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

Sciaenidae

The sciaenids are an economically important group of fish which inhabit the coastal waters and estuaries of West Africa. Most sciaenids are demersal in their habits (Fischer et al. 1981). The two species most commonly sampled during our study were *Fonticulus elongatus* and *Pseudotolithus senegalensis*.

In the lower estuary, sciaenid larvae were collected during all four sampling periods, but their abundance varied considerably. Larvae were most abundant during rising water (1,118 larvae/1,000 m^3) and numbers of larvae declined substantially during later sampling periods. Densities of 105 larvae/1,000 m^3, 30 larvae/1,000 m^3, and 39 larvae/1,000 m^3 were measured for periods of peak flood, declining, and low waters, respectively. Scheffers and Conand (1976) collected sciaenid larvae in the Gambia River estuary from January to October; largest catches were obtained during May. In Sierra Leone, peak spawning of *Fonticulus elongatus* occurred from December to February, while more limited spawning occurred during August-October (Longhurst 1969). Troadec reported that *Pseudotolithus senegalensis* spawned January-May and September-November in the Pointe-Noire region of the Republic of the Congo. These data suggest that sciaenid larvae may occur almost year-round in the lower estuary of the Gambia River.

While *Fonticulus elongatus* likely spawned year-round in the lower estuary, *Pseudotolithus senegalensis* probably spawned offshore (Fischer et al. 1981). Longhurst (1969) reported that larval *P. senegalensis* ranging from a few millimeters to a few centimeters in length were collected from coastal trawling grounds off Lagos, Nigeria, while *Fonticulus elongatus* larvae were collected in the Sierra Leone River estuary. Numerous ripe *F. elongatus* were

caught in the lower estuary during our study. This suggests that most sciaenid larvae caught during our study were F. elongatus not P. senegalensis.

Longhurst (1969) reported that juvenile F. elongatus occurred in the upper limit of a West African estuary in salinities of 1-3 ppt. In our study, sciaenid larvae occurred in low densities (1-9 larvae/1,000 m^3) in the upper estuary. They appeared during peak flood and declining water in salinities of 0.23 ppt and 2.15 ppt, respectively. No larvae were collected in the upper estuary during the rising- or low-water sampling periods.

Sciaenid larvae that were collected in the upper and lower estuaries ranged from 1.5 mm to 8.5 mm; most were small (1.5-3.0 mm) (Fig. 36). Quite likely, sciaenid larvae assume a demersal distribution early in life and are no longer vulnerable to pelagic sampling gear. This observation is supported by Longhurst (1969) who reported larval F. elongatus along with adults collected in benthic samples.

Cynoglossidae

Density of cynoglossid larvae in the lower estuary during rising water was 445 larvae/1,000 m^3, and decreased to 13 larvae/1,000 m^3 during peak flood. No larvae were collected in samples taken during the period of declining water. During low water, substantial numbers of larvae were collected in the lower estuary. Scheffers and Conand (1976) collected cynoglossid larvae March-July, September, and November-December. Aboussouan (1972c) found cynoglossid larvae near Goree Island (off Dakar, Senegal) during June-August.

No cynoglossid larvae were collected in the upper estuary during our study. Those larvae that were captured were generally small (2.0-4.0 mm)

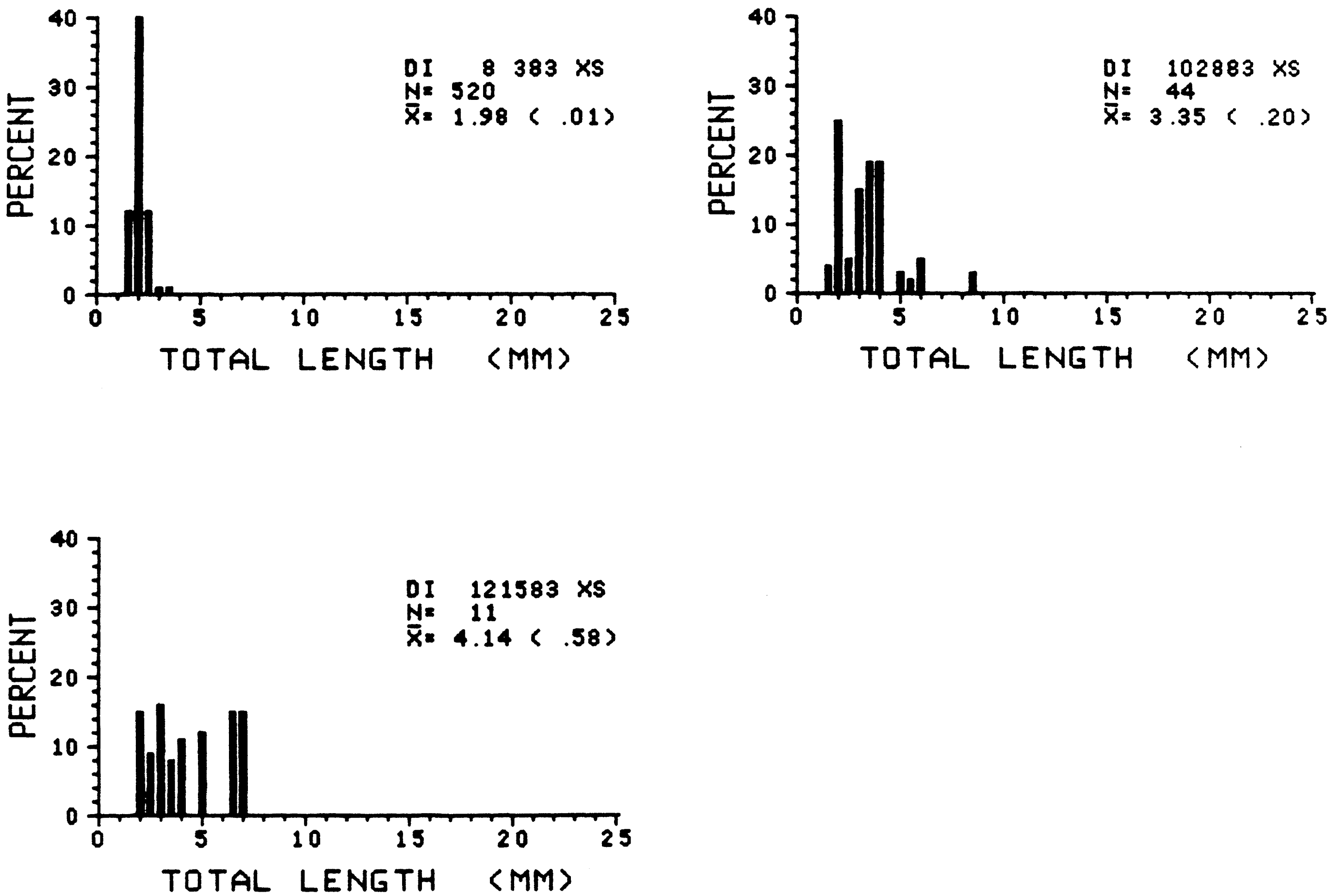


FIG. 36. Length-frequency histograms of larval Sciaenidae collected in the lower estuary study area, Gambia River, during 1983. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

(Fig. 37). Only one large larva (16 mm) was caught during this study. Paucity of large larvae suggests that cynoglossid larvae become demersal early in life.

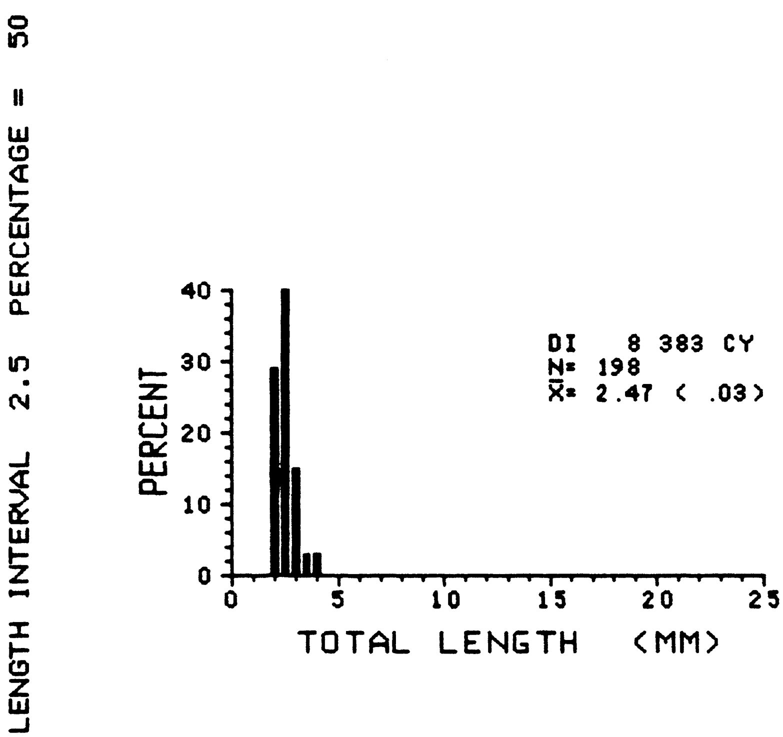
Mugilidae

The Mugilidae inhabit marine and fresh water. Mullet were abundant in estuarine waters of the Ivory Coast (Daget and Iltis 1965). Johnels (1954) collected several Liza falcipinnis in the freshwater portion of the Gambia River. In our study, mugilid larvae were collected in the lower estuary during all four field trips (Table 27). They were most common (128 larvae/ 1,000 m^3) during rising water. Densities on larvae declined substantially during peak flood to 17 larvae/1,000 m^3 and further to 3 larvae/1,000 m^3 during declining water. A slight increase in densities to 39 larvae/1,000 m^3 occurred during low water. These data suggest that Mugilidae spawned throughout the year in the Gambia River estuary. Mugilid larvae collected in the lower estuary ranged from 6 mm to 20 mm during rising water, and from 5 mm to 15 mm during low water (Fig. 38).

Other Taxa

Larval Blennidae were collected in small numbers in the lower estuary during all four sampling periods (Table 27). Lengths ranged from 2 mm to 8 mm. No blennid larvae were collected in the upper estuary.

Larvae of the Mullidae were collected in the lower estuary during rising water, peak flood, and declining water (Table 27). Lengths ranged from 7 mm to 14 mm.



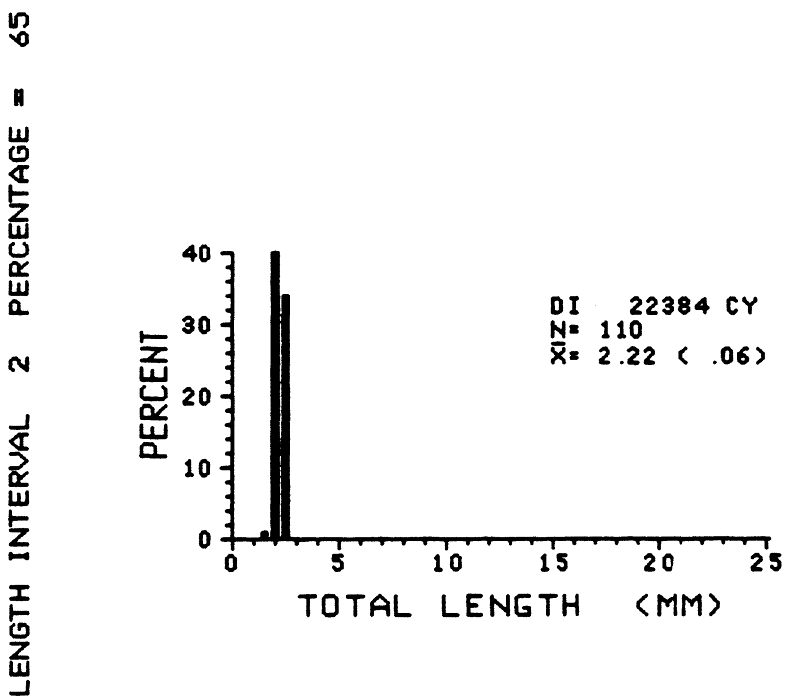


FIG. 37. Length-frequency histograms of Cynoglossidae larvae collected in the lower estuary study area, Gambia River, during August 1983 and February 1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

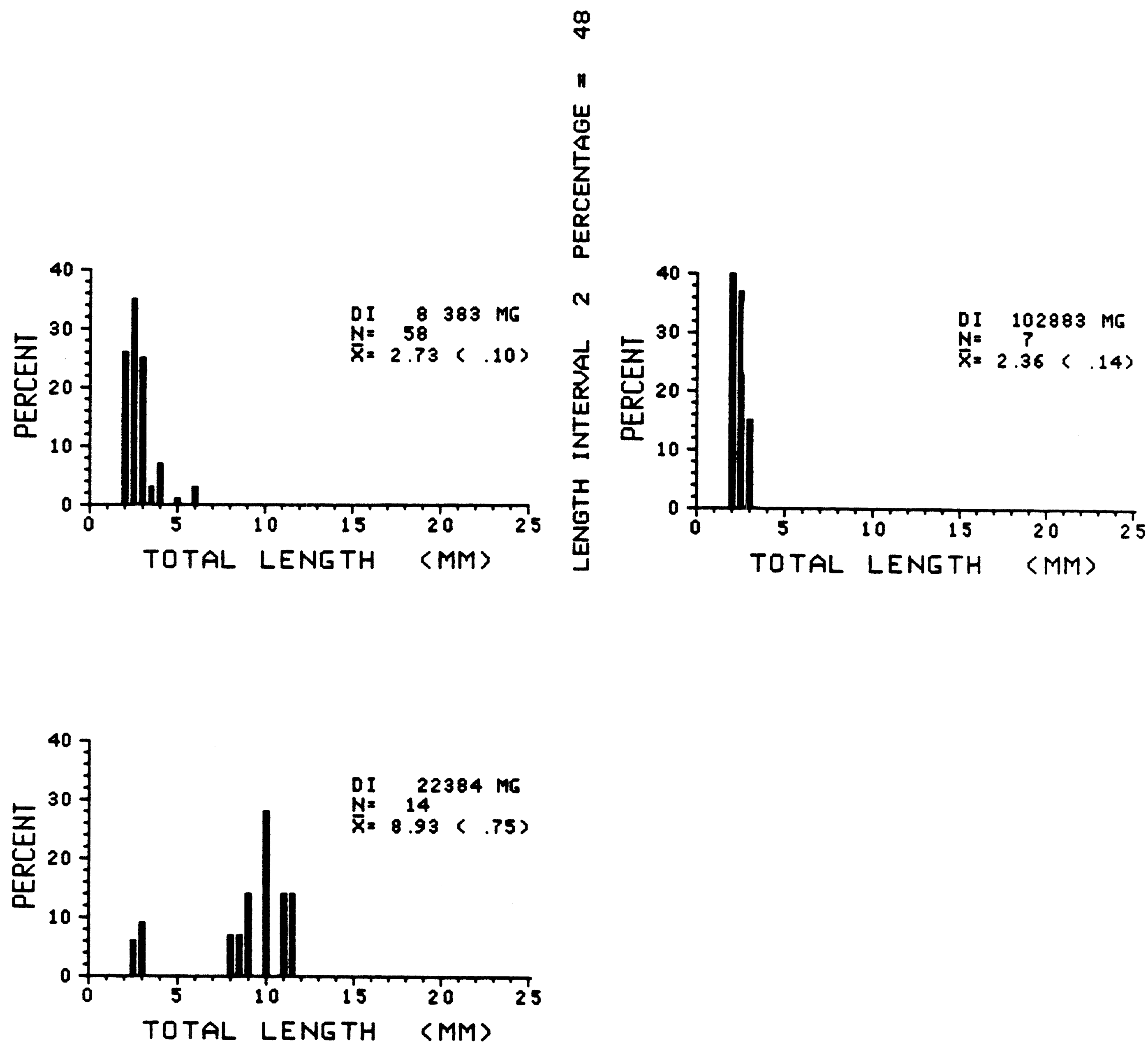


FIG. 38. Length-frequency histograms of Mugilidae larvae collected in the lower estuary study area, Gambia River, during 1983-1984. N = number of larvae collected, $\bar{X}$ = mean length. Standard error is given in parentheses.

Larval Carangidae occurred in densities of 3-7 larvae/1,000 m^3 in samples taken in the lower estuary during rising water, peak flood, and low water. Small numbers of larvae were also collected from the upper estuary and lower river during low water.

Larvae of the Elopidae and Syngnathidae were collected from both the upper and lower estuary. Larval Polynemidae were caught in the lower estuary during declining water.

FISHERY ECONOMICS

EXISTING SYSTEM

This section summarizes the major facts concerning artisanal fishing in the Gambia River Basin and along the Gambian coast. Estimates of sustainable yields were not made because of insufficient long-term catch data. The true economic value of the artisanal fisheries was difficult to assess because the product either was used as barter or moved to the marketplace without inclusion in government surveys. Nonetheless, estimates of economic values were made from available data. The value of the artisanal fisheries was also couched in terms of employment provided within the basin. Much of the material presented below was summarized from six reports which were produced as part of the Gambia River Basin Study. The primary source of material was from Josserand (1984), which included a three-week survey of artisanal fisheries in The Gambia and Senegal. Supporting material came from reports by Josserand et al. (1984), Saidykhan (1984), Dorr et al. (1983), Moll and Dorr (1985) and van Maren (1985). The authors of these documents drew heavily upon the statistics of fish catches provided by the Fisheries Department, Gambian Ministry of Water Resources, and the Livestock Service, Senegal.

Artisanal Fisheries

Gambian Atlantic coast -- A very active artisanal fishing community exists along the Gambian coast. The entire coast has numerous small fishing fleets composed of motorized canoes which are generally between seven and ten meters long. The largest and most active community is centered near Brufut. Upward of 600 canoes operate along the coast, employing as many as 3,000 fishermen and their helpers (Josserand 1984). The artisanal fishermen caught

slightly more fish between July 1982 and June 1983 than did the commercial fishing companies; 8,116 metric tons were taken by artisanal fishermen versus 7,275 metric tons for commercial harvest (Josserand 1984). The fish catch was diversified (see Annual Yield under General Discussion), and included pelagic fish, demersal fish, and crustaceans. The dominant catch by far was bonga (*Ethmalosa fimbriata*), accounting for 5,271 of the 8,116 metric ton catch (Josserand 1984).

Approximately two thirds of the coastal artisanal fishermen in The Gambia were foreigners. These were primarily long-term residents who in many ways could be considered Gambians. Some of the fishing was seasonal with Senegalese fishing along the coast during the dry season after the crops had been harvested. The predominant method of fishing was with gill nets and surround nets.

The largest impediment to maintaining a successful fishery for most of the coastal artisanal fishermen has been marketing. Once the perishable fish have been landed on the beach and cleaned, the lack of an efficient mechanism to transport the product to market was evident. Processing of fish product was poor, often utilizing the wasteful sun-drying technique. Until recently, the road network leading to the fishing beaches was poor, but now has been vastly improved. But coordinated transportation of fish products to market was still lacking by early 1984. Experience in Senegal has shown that demand for fish products in interior villages was very high, as long as the product can be brought to market.

Gambian estuarine and river fisheries -- This fishery was considerably smaller than the coastal artisanal fishery. The official listed catch between July

1982 and June 1983 was 1,242 metric tons (Josserand 1984). The river has been divided into two regions for survey by the Fisheries Department: the lower river which is downstream from Yelitenda and the remaining segment as the upper river. The 1,242 ton catch was evenly divided between the two regions, with the lower river taking 604 metric tons (Josserand 1984). This catch was rather diverse and included marine as well as freshwater fish (see Annual Yield under General Discussion).

The actual species of fish caught at any one location was seasonally dependent, with temperature and salinity affecting the location of each species. The Gambian Fishery Department estimated the number of artisanal fishermen working the estuarine and river fisheries at 1,800; 300 in the upper river and 1,500 in the lower river. Josserand (1984) has set this total closer to 3,000 as a result of his field survey of the artisanal fishing community. Both estimates included the three hundred shrimp fishermen associated with National Partnership Enterprises, Ltd. (NPE). The discrepancy between the two estimates probably lies in the seasonal nature of the occupation. Many artisanal fishermen turn to farming during the rainy season and back to fishing after the crops are harvested.

In the lower river, most of the fishermen (90%) were Gambians, while in the upper river they were predominantly foreign (70%) (Josserand 1984). These foreign fishermen were primarily Senegalese and Malian, with representation from Guinea-Bissau. All of the artisanal fishermen tend to use similar techniques irrespective of national origin. These techniques include shifting from fishing in the main channel to the flood plains and bolons and back to the main channel depending upon the season.

One segment of the artisanal fishery that is totally untabulated is the shellfish harvest. A significant bivalve population has been observed growing

on the proproots of many Rhizophora mangroves. This fishery provides a substantial amount of local food to the lower river communities, but is not included in the fishery surveys. This lack of inclusion may originate from the fact that oyster and other shellfish harvests are conducted by women who work alone. These women often just wade into the estuary, collect their harvest, and trade or sell it locally.

The same problems of lack of marketing and wasteful processing that plague the estuarine and river artisanal fishery also plague coastal fishery. Road networks in The Gambia are rapidly improving, but this is primarily in response to the groundnut industry. Roads from the main highway to the river are usually in poor shape and deteriorate quickly during the rainy season. Roads in the lower river section through the mangroves are few and far between. While the fishermen know that fish catches have declined over the past 10 to 15 years, they feel that marketing problems remain the biggest impediment to expanding the artisanal fishery (Josserand 1984).

Senegal -- Fishing activities along the Gambia River and tributaries in Senegal were primarily conducted by a series of small villages on the river. Josserand (1984) gave a complete list of these villages including a breakdown by tributary. A major section of the Gambia River was not fished because it passes through Niokolo Koba National Park.

While artisanal fishing is considered a rather prestigious occupation in Senegal, the intensity of fishing effort is much lower than in The Gambia. Small fish catches were apparently consumed primarily within the village of their origin. Marketing problems were extreme and prevented any large-scale shipping of fish among villages. Similar to The Gambia fisheries, demand

vastly outstrips supply. A major difference between The Gambia and Senegal is that Senegal has a better national road network which allowed the development of substantial marketing of saltwater fish inland. Thus, much of fish sold at the two main population centers in eastern Senegal, Tambacounda and Velingara, was marine fish. These marine fish were readily sold at prices competitive to beef (Josserand 1984).

The most complete set of information concerning artisanal river fish yields is through a market survey of Kedougou conducted by the Livestock Services. In 1982, approximately 69 metric tons of fish were marketed in Kedougou. Forty-five tons were dried fish, eighteen tons smoked fish, and only six tons fresh fish.

Most artisanal fishermen interviewed by Josserand (1984) stated that fish were more abundant 10 to 15 years ago. These fishermen attributed the declining catches to the drought and the lack of inundated flood plains as spawning sites. The combination of poor catches, inadequate preservation techniques, and extremely bad marketing in eastern Senegal has contributed to the demise of river fish in the large regional markets.

Guinea -- Guinean fisheries contributed only a small fraction of local food supplies, unlike the The Gambia or Senegal. Also, the fisheries were seasonal in nature and thus contributed food to the local diet for only a portion of the year. The Guinean artisanal fisheries were viewed as a minor resource which would only be enhanced by the river basin development program.

Industrial Fisheries

The primary economic benefit received by the local economy from industrial fishing is derived through foreign exchange and domestic employment. The latter is mostly facilitated by artisanal fishermen contracted to industrial fish processing and export companies. Economic revenues from industrial fishing come from foreign vessel fishing fees, export taxes on fish products, and return of some of the export value of the catch to the local economy.

Recent revenues from these sources illustrate the relatively small portion of the FOB catch value that is reflected back into the local economy. Additionally, most companies tend to undervalue their catches and thus reduce export taxes. The values are probably minimums and could be considerably higher.

While The Gambia exports a proportion of the fishery products taken from its waters, it also imports a considerable amount of high-value fish products. Approximately 600-700 metric tons or about 10% of the total export volume is imported annually. Unfortunately, these imports are of high-priced products and are equal to almost one half of the value of the exports. These imports include mainly canned, salted, smoked, or dried high value fish.

Domestic companies -- The largest Gambian-owned fishing company is National Partnership Enterprises, Ltd. (NPE) based in Banjul. This company uses a variety of fishing techniques including contracting of artisanal fishermen to exploit the pink shrimp (*Penaeus duorarum*) and high-value demersal fish stocks (e.g., sole). NPE processed about 415 metric tons of fishery products from July 1982 to June 1983, of which about 227 metric tons were shrimp (van Maren 1985). Between July 1983 and June 1984, the NPE-processed

shrimp catch increased to 412 metric tons (van Maren 1985). Over 300 fishing canoes use stake nets and ancillary fishing gear in the harvest of NPE shrimp. NPE sponsored shrimp and demersal finfishing employed upwards of 1,000 people in The Gambia during peak fishing periods. An additional unquantified number of people were employed in the fishing supply, service, and processing sectors. The NPE catches are high-value products with an annual export value of 2-4 million dalasis. The fishing activities of NPE provide an excellent source of foreign currency for The Gambia because about 95% of its product is exported.

The other major industrial fishing company that is Gambian-owned and also located in Banjul is the Fish Marketing Company (FMC). This is a nationalized company established in 1977 to take over the premises of a bankrupt Japanese firm (Josserand 1984). FMC has the charge of issuing export permits for fish products taken from Gambian waters. The company also handles a small amount of fish products which are purchased from artisanal fishermen for export. The volume of this product has ranged from 400 metric tons in 1980 to 102 metric tons in July 1982-July 1983. Most of the FMC purchases have been from the marine coastal artisanal fishing sector. If current plans for FMC are realized, it will become the dominant company in the industrial fishing sector. Through a $20 million (U.S. dollars) financing agreement with the African Development Bank and European technical assistance, FMC will obtain an extensive fleet of trawlers, a jetty, and processing facilities. FMC, to be renamed the National Fish Marketing Board, plans to fish for sardines (<u>Sardinella</u>), bonga (<u>Ethmalosa fimbriata</u>), and other marine coastal species.

In addition, FMC expects to purchase 30% of its total product from artisanal fishermen for processing in its facilities which would represent a major increase in economic benefit to the economy and people of The Gambia.

Foreign companies -- The dominant foreign-owned company fishing Gambian waters and operating out of Banjul is the Ghanaian-owned Seagull Cold Stores, Ltd. This company paid approximately 78% of all fees and taxes collected by the Gambian government from foreign fishing concerns. Seagull catches also comprised more than 80% of the total industrial fish harvest in Gambian waters during 1983 (Josserand 1984). Between July 1982-June 1983, Seagull processed 5,944 metric tons of the total 7,275 metric tons of industrial fish product. Nearly all of this product was sardines which were exported to Ghana because there is a limited market for these fish. Seagull is a totally foreign-owned and operated company employing considerable foreign labor. As a result most of the benefit of this company's activities to The Gambia comes from foreign exchange associated with fishing fees and taxes.

Up to eight smaller foreign fishing companies have fished Gambian waters since the early 1970s. During July 1982-June 1983, their combined fleet totaled eleven trawlers which took about 800 metric tons of fish. This total represents about 11% of the total industrial catch from Gambian waters. Josserand (1984) estimated the annual value of the total catch in the tri-national coastal waters of Senegal, The Gambia, and Guinea to exceed 10 million dalasis. But the actual value of the portion of fish caught in Gambian waters by these companies was estimated at less than one tenth of their total catch in these West African waters.

ECONOMIC STATUS OF FISHERIES

This section summarizes available information on the current economic value of fisheries in the Gambia River, and offers predictions of economic yield from development projects on the river. An overview of the existing fisheries economics in the region has not been developed. An impediment to developing that overview is that data on both industrial and artisanal catch, effort, and value are incomplete. Although data have been compiled since the mid-1970s, the results are not consistent for any fishing sector or year. A major problem is the limited resources available to the governments in order to conduct fishery surveys and data analysis. While some of these limitations are technical, the majority relate to inadequate budgets and manpower.

Included in this section is information on the existing industrial fisheries, a summary of their recent catches and values to the local economy, and the prospects for future expansion. No attempt was made to predict sustainable yields because long-term data needed to do this were not available. Senegal and Guinea are not included in this discussion because there were no industrial fisheries on the Gambia River in these countries.

The information used to compile this section was drawn from three general sources: GRBS, data compiled in publications of the Fisheries Department (The Gambia), and Josserand (1984). This section has been divided into two major parts: an analysis of the existing fisheries and their economics, and predicted effects of development activities on these fisheries. In both instances, benefits to the local economy are obtained either, (1) directly through sale of fishery products or by taxation on fishing (fees), catch, and revenue, or (2) indirectly through employment in the fishing or support sectors. In the upper areas of the basin (upper freshwater river and headwater

zones), fish products are most often consumed directly by fishermen and their families or traded for other goods and services.

Industrial Sector

Finfish fisheries -- Data from the Gambian Fisheries Department and an evaluation of fisheries by Josserand (1984) show that total landings in metric tons for The Gambia were: 1978 - 32,085, 1979 - 21,374, 1980 - 24,496, 1981 - 22,102, and 1982 - 17,081. Of these totals, the industrial catch comprised 62%, 48%, 44%, 44%, and 44%, respectively, each year.

Catch and economic value data from 1981 and 1982 were considered fairly representative of fishing activity in the industrial sector, but are the only years for which catch records are relatively complete. Total industrial fishing catch was 9,624 metric tons in 1981 and declined to 7,377 metric tons in 1982. Fishing fee receipts to the Gambian government in 1981 totaled 448,732 dalasis plus an additional 60,000 dalasis in export taxes (Josserand 1984). Total 1981 fishing fee and tax receipts to the government of The Gambia obtained from industrial fishing approached 500,000 dalasis. The export value of the 1981 industrial catch is not known but, Josserand (1984) placed the export value of the 1982 catch at more than 3 million dalasis. This extrapolates to an export value of 4 million dalasis for the 1981 catch. Because these catches were sold by foreign-owned companies in markets outside of The Gambia, little of their value was returned to the local economy beyond the fishing fees and export taxes paid to catch and export these fish. If the export value of the 1981 finfish catch was about 4 million dalasis and the government received 500,000 dalasis in fishing fees and taxes, this indicates

that The Gambia received about 12% of the value of the fish taken from its waters that year by the industrial fisheries.

Using the 1981 relationship of 52 dalasis in fees and taxes received per metric ton of fish caught, rough estimates of the value of the industrial fish catch to the local economy are: 1978 - 1,044,472 dalasis, 1979 - 535,340 dalasis, 1980 - 559,104 dalasis, 1981 - 500,448 dalasis, 1982 - 383,604 dalasis, 1983 (projected) - 388,336 dalasis. Although only estimated values, the range (0.3 - 1.0 million dalasis/yr) is probably accurate; ten-fold increases or decreases are not expected. These figures show that the value of the industrial catch (and revenue to the Gambian government through fees and taxes on this catch) in 1983 had declined to about one-third that of the 1978 yield from the fishery. These estimates show that the decline in catch volume and value from 1978-1983 is an indisputable and significant problem in the industrial fishing sector. It is suspected that the problem relates more to a decline in fishing effort resulting from lack of economic resources to sustain the fishery than to a depletion of fish stocks.

Recent estimates of coastal marine stocks or sustainable yields were not available. But, during the late 1970s, maximum sustained yield (MSY) in coastal waters near The Gambia was estimated at 4,000 to 8,000 metric tons for demersal species and 30,000 to 50,000 metric tons for pelagic species (Scheffers 1976; King 1979). Even if these estimates were high and stocks have declined since that period (no biological evidence was found to substantiate a decline), these figures suggest that both the demersal and pelagic fisheries could support considerable increases in fishing effort and harvest.

Prior to increased investments and exploitation, a study should be conducted to establish maximum sustained yield for target coastal fish

species, both demersal and pelagic. Also, this study should evaluate the relationship between economic investment and yield and establish the maximum economic yield (MEY) possible for these fisheries. Given MSY and MEY, the coastal industrial fishing sector would be guided in its efforts to increase its fisheries and economic return within the biological and economic constraints of the system.

Concurrent with the possibilities for increased fishing pressure and annual harvest of stocks from Gambian as well as adjacent coastal waters, is the need to improve fishing gear and methods, product handling and processing techniques, and marketing of the product. Much of the gear currently deployed is antiquated or in need of repair which reduces the efficiency and yield per unit of fishing effort. A significant portion of the catch is lost to spoilage, bruising, or damage prior to or during processing. Losses sustained to the catch in the artisanal sector prior to marketing were estimated at 30%. Currently, the largest problem in both the industrial and artisanal fishing sectors in The Gambia is losses sustained during transport to processors or markets because of inadequate roads and marketing networks. Since 1978, the combined catch from the industrial and artisanal fisheries has dropped from 32,000 metric tons to 15,000 metric tons. Josserand (1984) attributed much of this decline to problems associated in the handling, distribution, and marketing of fish products.

<u>Shellfish fisheries</u> -- Shellfish harvested from the Gambia River and adjoining coastal waters include molluscs (oysters, cockles, the large marine gastropod <u>Symbium</u> spp. locally referred to as "yeat," and cuttlefish) and crustaceans (crabs, lobsters, and shrimps). The bulk of the oysters, clams,

yeat, and cuttlefish were harvested by the artisanal fishermen and locally consumed. Export of these shellfish was insignificant. Lobsters and crabs were caught by artisanal fishermen, with some of the lobsters sold to NPE for processing and export. But the size and economic value of the industrial lobster fishery is small relative to the other (finfish and shrimp) export fisheries. By far, shrimp are the most important shellfish product to both the industrial and artisanal shellfishing sectors, because the shrimp are caught by artisanal fishermen fishing under contract to NPE.

Oysters (Crassostrea gasar) and cockles (Anadara senilis) are harvested by artisanal fishermen and are only sold on local markets, as no industrial fisheries exist for these shellfish. Yeat appear in the incidental catch of industrial vessels trawling for demersal fish. The yeat are purchased by artisanal fishermen who meet the trawling vessels at sea and return to coastal fishing villages where the snails are distributed and sold locally.

Young cuttlefish (Sepia officinalis bierreda) occur in the estuary of the Gambia River but are too small to be of commercial value. Large adult cuttlefish live in deep offshore ocean waters but migrate inshore during December to May to spawn. During their appearance inshore, cuttlefish are trawled and sold to an industrial processor (NPE) in Banjul. Exact numbers are not available, but the annual export and value of cuttlefish is considerably less than 60 metric tons and 123,322 dalasis (Josserand 1984).

Approximately 0.2 metric tons of lobsters were exported by NPE during July 1982-June 1983 and were valued at 1,320 dalasis. These crustaceans are caught by artisanal fishermen and sold to NPE. Josserand (1984) stated that maximum sustained yield of these crustaceans in coastal waters near the Gambia River should equal at least 1,000 metric tons. Given the above catch value of

6,600 dalasis/metric ton, an annual catch of 1,000 metric tons would be valued at 6,600,000 dalasis. Regardless of the inexactness of these numbers, it is evident that considerable potential exists to expand the lobster (and crab) fishery given the investment of equipment, labor, and marketing efforts.

The only crabs in the Gambia River estuary which attain sufficient size to be of potential commercial value are the blue crabs (*Callinectes* spp.). A substantial commercial fishery for these crabs exists in the United States, but the blue crab is underexploited in West African waters. Presently, only artisanal fisheries for these crabs exist in the vicinity of the Gambia River, and most of the catch is consumed by the fishermen or their families. Estimates are not available for the value of this catch. Efforts should be made to explore development and export of blue crab as an industrial fishery.

The primary and most important industrial shellfish fishery is that of shrimp. Although several species comprise the oceanic catch, catches in the Gambia River are confined to the estuarine reaches of the river and are limited almost exclusively to the pink shrimp, *Penaeus duorarum*. Van Maren (1985) presented findings on the distribution and biology of pink shrimp in the Gambia River and adjacent coastal waters. Data on shrimp catch and value were presented in Josserand (1984) and van Maren (1985).

Shrimp are captured in stake nets by artisanal fishermen in the estuary of the Gambia River. The catch is sold to NPE which processes and freezes the shrimp in their Banjul factory. Most of the frozen shrimp are transported in refrigerated trucks to Dakar, Senegal, for export to Europe. Josserand (1984) indicated that about 227 metric tons of shrimp were processed by NPE during July 1982-June 1983, and placed the export value of this catch at 2-3 million dalasis. Annual catch increased to 412 metric tons for the July 1983-June

1984 period (van Maren 1985). Additionally, an unquantified but small amount of the NPE shrimp product is sold locally. Estimates of maximum sustainable yield of shrimp from the Gambia River itself are not available, but oceanic stocks are likely underexploited at the present. Efforts should be made to estimate both oceanic and riverine shrimp stocks and sustainable yields so as to establish annual catch quotas to more fully exploit this valuable resource. The potentially severe impact of river basin development on the biology, distribution, and abundance of estuarine stocks was discussed extensively by van Maren (1985) and is discussed later in this report along with economic implications of this impact.

Artisanal Sector

As with the industrial sector, the artisanal fisheries can be subdivided into finfish and shellfish. In some instances, artisanal fishing is closely linked to the industrial fishing sector as is the case of the shrimp fishery.

Finfish fisheries -- The artisanal finfish fisheries on the Gambia River can be separated into three categories: marine coastal fisheries adjacent to the river mouth, estuarine fisheries, and freshwater fisheries. The Fisheries Department of The Gambia has compiled catch-assessment data since the late 1970s. Beginning in 1980, the department has conducted monthly catch surveys and an annual frame survey on an intermittent basis to evaluate catch, ownership of gear deployed, and nationality of fishermen operating in Gambian waters. Data on total fishing effort or by specific gear were not compiled. In early 1982, Le Service des Eaux et Forets (Dakar, Senegal) initiated a limited catch survey in the upper freshwater portion of the river in Senegal,

but more long-term data were required for use in this analysis. Additional data on catch, effort, and economic value of fish taken from the Gambia River were not located. A detailed description of the catch survey programs in the basin was presented in Dorr et al. (1983). Josserand (1984) conducted an economic analysis of Gambia River fisheries and discussed the implications of river basin development on both the industrial and artisanal fisheries.

By far, the major proportion of the catch and economic value of the Gambia River Basin artisanal fisheries comes from the marine coastal sector. The marine coastal catch has fluctuated from 6,000 to 13,000 metric tons annually between 1978 and 1982. These catches have comprised 64-89% of the total artisanal fishery catch during these years. Assuming an average 1984 market price of 2.0 dalasis/kg, the economic value of this catch has ranged from 22 million dalasis in 1978 to 12 million dalasis in 1982. Because the catch is sold on local markets rather than exported, economic revenue from the locally-sold marine-coastal artisanal fishery catch is more than 10-fold greater than those obtained from the industrial fishery catch. In 1982, the economic value of the marine coastal artisanal fishery to the local economy was 30 times that of the industrial fishing sector and 5 to 6 times that of the riverine artisanal fishery. Given the recent decline in marine coastal catch, the current annual value of this catch is probably about 10 million dalasis.

Indirect evidence suggests that stocks presently targeted by the marine coastal artisanal fishery could sustain a considerable increase in fishing pressure and annual yield, although exact values of these increases remain to be established. In addition, improvements in fish handling, processing, and marketing techniques could significantly increase economic return on existing

levels of catch and investment. These improvements relate to reductions in fish spoilage, more rapid and efficient transportation to existing markets, and expansion to include additional markets.

Most stocks presently targeted by the marine coastal artisanal fishery will remain relatively unaffected by the barrage and dams proposed for the river system, with the possible exception of *Ethmalosa fimbriata*, the bonga as it is known locally. The potential reduction in stocks of *Ethmalosa fimbriata* poses the most immediate and severe threat to the marine coastal artisanal fisheries from river basin development activities. Previous sections of this report discussed the dependence of bonga on estuarine conditions in relation to spawning, nursery, and feeding requirements. The economic implications of their findings are discussed later in this section.

A valuable contribution of the marine coastal artisanal fishery to the local economy is through employment. Josserand (1984) estimated that 2,600-3,000 fishermen are involved in this fishery and that an additional 10,000-15,000 ancillary jobs are generated by fishing activities in this sector.

The present riverine artisanal fisheries can be divided into two sectors: estuarine and freshwater. Catch assessment data for these sectors in The Gambia appear in Fisheries Department databases compiled for their Lower (estuarine) and Upper (freshwater) River Divisions, respectively. Comparison of catch and yield data for these sectors from January-December 1980 and July 1982-June 1983 reveals that the estuarine catch (Lower River Division) declined from 2,406 metric tons to 605 metric tons during the 2 1/2-year interval between these periods. However, catch from the freshwater portion (Upper River Division) of the river in The Gambia remained nearly constant at about 630 metric tons per annum. If an average value of 2.0 dalasis/kg for estuar-

ine fish and 1.5 dalasis/kg for freshwater fish is assigned to this catch, then the total riverine artisanal catch was valued at 5,758,500 dalasis in 1980 and declined to 2,165,500 dalasis for the 1982-1983 period.

Two factors could account for the stability of the freshwater fisheries in the face of the decline in estuarine catch. First, although both sets of catch data were compiled during a 12-month period, the period of record began and ended at different points in the annual hydrological regime. Previous sections of this report documented that several species of fish, including some targeted by the artisanal fishery (e.g., sardines, bonga, catfish) appear to move into and out of the estuary in relation to the annual flood cycle. Part of the difference between the 1980 and 1982-1983 estuarine artisanal catches may be attributed to seasonal differences in abundance, distribution, and catch of fish rather than an overall decline in abundance of fish.

The second factor is that since 1980, when the boundary between the Lower and Upper River Divisions was established at the interface of estuarine and fresh waters near Kaur, the drought and reduced streamflows have allowed salt water to advance nearly to Kuntaur, a distance of 61 km upstream from Kaur. The upper estuary is a region of high productivity, relative to the freshwater river, and the effect of this transferal of a region of high productivity would be to restructure the proportional distribution of catch between the two divisions. The result would be an apparent reduction in the estuarine division catch and a maintenance of the freshwater division catch, as was observed. A detailed comparison of monthly catch and effort data is needed to substantiate the apparent decline in estuarine artisanal fishery catch in the face of stable freshwater fishery catch. However, without a

doubt, annual catch and economic yield of Gambian freshwater fisheries has declined over the past 5 years.

The above figures show that the current economic value of the estuarine artisanal fishery appears to have declined to about 1 million dalasis per annum. The value of the Gambian freshwater fishery is also valued at about 1 million dalasis, annually. The total value of the 1982 artisanal catch of finfish to the Gambian economy was roughly 14.4 million dalasis. Of this total, the artisanal marine coastal fishery contributed about 12 million dalasis, the inland or riverine artisanal fishery about 2 million, and the industrial fishery about 0.38 million dalasis. The 1982 catch for each sector was 6,196 metric tons, 3,508 metric tons, and 7,377 metric tons, respectively. The return per kilogram of fish was 2.0 dalasis/kg, 1.6 dalasis/kg, and 0.05 dalasis/kg, respectively, for each sector. These data show that, in terms of fish biomass removed from the system, the economic return to the local economy is highest for estuarine artisanal fisheries, followed closely by the freshwater artisanal fishery, with industrial fisheries taking a distant third to the others. But in contrast, local economic investment in fishing gear, supplies, and services for the industrial sector is minimal because the vessels are foreign-owned and operated. Therefore, the approximately 500,000 dalasis per annum obtained by the local economy from fishing fees and taxes on the industrial sector is relatively free of investment costs and represents nearly pure profit to the local economy. At the same time, while the artisanal sector must make economic investments in gear, supplies, and services, these fisheries are technically simple and rudimentary in design and extent. Cost per annum per metric ton of fish caught by the artisanal fishing sector is not known but is undoubtedly low; the benefit/cost ratio could exceed 10:1.

Although investitures in equipment and supplies required for initial entry into the occupation are relatively costly and would initially reduce the benefit-to-cost ratio, most artisanal fishing is done by well established family or other structured groups, and new entries into the sector are infrequent, especially during present conditions of economic depression, drought, and reduced riverine fish production. Therefore, present investment costs associated with acquisition of new gear are minimal in the artisanal sector. As a result, the benefit-to-cost ratio in this fishing sector is near its maximum.

As with the coastal fisheries, the riverine artisanal fisheries contribute to local employment. Based on 1983 frame survey statistics (unpublished data, Fisheries Department, Banjul, The Gambia), about 1,500 jobs are associated with the estuarine (Lower River Division) fisheries. About 300 jobs are associated with the freshwater (Upper River Division) riverine fisheries.

The situation in Senegal is considerably different from that of The Gambia. Catch statistics have not been compiled for the Senegalese portion of the river prior to 1984. But during February 1984 field studies, Josserand (1984) noted that nearly all fish seen in the markets in Tambacounda and Velingara were of marine origin. This observation suggests that most fish caught in the western portion of the river are sold or bartered and consumed locally. Artisanal fish catches from this portion of the river appear to be small and of minor economic importance outside of the immediate fishing community. The river enters the national park in the southeastern region of Senegal and fishing between this point and the border with Guinea is centered near Mako and Kedougou. Based on personal observations and analysis of limited data from the first 6 months of 1984, Josserand (1984) stated that the

daily quantity of locally-caught fish sold in the Kedougou market probably does not exceed 25 kg. Extrapolation of this daily market sale to annual catch suggests that no more than 9 metric tons of fish were caught and sold in this region. Assuming slightly lower yields for areas outside of Kedougou, the total annual yield from Senegalese portions of the river between the national park and Guinea that was sold on local markets was probably less than 15 metric tons. Using a February 1984 market value of 300 to 400 CFA/kg (Josserand 1984), the value of this catch was 2.7 to 3.7 million CFA. An unquantified but undoubtedly significant portion of total fish catch is probably consumed without ever reaching the markets.

Although artisanal fishermen were observed in the Guinean reaches of the river, data on catch or marketing of fish were not available. It is not possible at this time to make an accurate estimate of the catch or economic value of fish taken from the Gambia River in Guinea. However, the total market value of fish taken from the Guinean portion of the Gambia River (excluding tributaries) is probably less than that of fish caught and marketed from the Senegalese portion of the river, considering that the river is reduced in size and human populations are no larger in its Guinean reaches than in the vicinity of Kedougou, Senegal.

Shellfish fisheries -- Shellfish harvested by artisanal fishermen included oysters, cockles, yeat (*Symbium* spp.), cuttlefish, lobsters, crabs, and shrimp. The bulk of the lobster, shrimp, and cuttlefish catch is sold to industrial processors for export. Fishermen and the local economy benefit from employment and sale of this catch to the processors and thereby obtain a portion of the total value of the catch. However, it is safe to assume that

this yield to local economics is considerably less than one-half the export value. Josserand (1984) estimated the industrial export of crustaceans excluding shrimp as 60.7 metric tons for the period July 1982-June 1983 valued at 124,642 dalasis. The above assumptions and figures suggest that perhaps 62,000 dalasis ($32,000) may have entered the local economy during the 1982-1983 period from sale of artisanally-caught shellfish to industry for export. An additional but unknown quantity of lobsters, shrimp, and cuttlefish were sold on local markets rather than exported. Most likely, the input to the local economy was nearly insignificant relative to the combined total for the other artisanal fishing sectors (i.e., the combined economic value of the finfish and other shellfish catch).

The remaining shellfish products which were caught and marketed locally by the artisanal fishery included oysters, lobsters, cockles, yeat, and crabs. Of these, oysters and yeat probably contributed most to the local economy. Josserand (1984) suggested that perhaps 150 metric tons of oyster meat was harvested and marketed locally each year. Most of this product was smoked although some was marketed fresh. During 1983-1984, the price paid for oysters purchased from local vendors was about 6 dalasis/kg. At this rate, the total value of the oyster catch approached 900,000 dalasis per annum. At nearly 1 million dalasis annually, the impact of the oyster fishery on the local economy must be on the same scale as that of the industrial finfish catch and the inland or riverine fisheries. If earlier calculations regarding artisanal shrimp fishing and economics are accurate (2 million dalasis or less per annum) then the contribution of the artisanal oyster fishery approached 50% or more of that contributed by the shrimp fishery to the local economy. Because oysters require the presence of salinity and a substrate (mangrove

roots) for economically viable existence, this fishery would be eliminated in all areas above the Balingho impoundment, and in any hypersaline waters below the barrage. Although substantiating data are lacking, the bulk (>85%) of the present oyster harvest probably occurs downstream of Balingho. If these assumptions are correct, the oyster fishery would sustain less than a 15% (150,000 dalasis) reduction in annual input to the local economy as a result of construction of the Balingho Barrage. Existing oyster fisheries in unaffected portions of the estuary could be expanded to compensate for upstream losses.

Cockles and cuttlefish were harvested by artisanal fishermen and sold in local markets. The economic value of these catches, while unquantified, was probably small in comparison with the contribution of other shellfish and finfish products to the local economy. The extent to which fisheries and markets for these products might be expanded to compensate for losses in other artisanal fishing sectors is not known but should be evaluated.

Drammeh (1982) noted in a summary of catch statistics recorded by the Fisheries Department of The Gambia that about 96 metric tons of yeat (the marine gastropod Symbium spp.) were landed by the marine coastal artisanal fishery during 1981. These marine gastropods were caught by industrial fishing vessels in trawls for demersal finfish and sold to artisanal fishermen who met the trawlers at sea and purchased the yeat, which were then sold on the local markets. Assuming that the dressed weight of this catch (about one-half the total weight or about 50 metric tons) was sold for 3 dalasis/kg, this catch would have been valued at 150,000 dalasis. Because the animal and the fishery are strictly marine, they would not be directly affected by changes in the river.

Crabs are caught by artisanal fishermen but not widely marketed. Rather, they are consumed by the fishermen or their families. Crabs were occasionally sold in the local markets but quantities available were limited (no more than a few crabs at any given time) and supply highly unpredictable. Given the extent of the blue crab fisheries in the United States and elsewhere, further investigation should be made into the potential for expanding the artisanal crab fishery.

The contribution of the artisanal shrimp fishery in relation to the export of this product was discussed earlier in relation to the industrial shrimp fishery. The total value of the 227 metric tons caught during 1982-1983 by artisanal fishermen working under contract to the major industrial exporter (NPE) was estimated to be 2 to 3 million dalasis by Josserand (1984) and 3.8 million dalasis by van Maren (1985). The monies received by the fishermen for their catch must have been considerably less than these figures for NPE to have operated at a profit. Van Maren (1985) noted that artisanal fishermen were paid about 6 dalasis/kg for shrimp that were exported at about 12 dalasis/kg, or at a rate equal to about half the export value of the catch. Given these figures, the annual contribution of artisanal shrimp fishing to the local economy could be conservatively estimated at 1 to 2 million dalasis per annum. The exact amount would depend on the volume of the catch, processing costs, external market prices, and the value of the dalasis against other currencies. During the period July 1983-June 1984, NPE processed 412 metric tons of shrimp, a 185-ton increase (81%) over the preceding period. The export value and revenue to the local economy of the 1984 shrimp catch will not greatly exceed 5 million and 2.5 million dalasis, respectively.

An additional consideration associated with the contribution of the riverine shrimp fishery to local economics is the aforementioned employment of nearly 1,000 people in jobs related to shrimp fishing for NPE. Josserand (1984) estimated that about 60 man-years of employment were generated annually in full-time artisanal shrimp fishing. To this must be added employment and monies received by sectors servicing and supplying these fishermen (excluding costs of netting gear which is provided to the fishermen by NPE). Profits realized by the artisanal fishing sector and local economy through the catch and sale of shrimp to industrial processors then spread throughout both the fishing and support sectors.

DEVELOPMENT IMPLICATIONS AND TRADEOFFS

Overview

Economic considerations associated with the existing fisheries of the Gambia River were discussed in the preceding sections. Those findings form the perspective in which the economic implications and tradeoffs presented below are couched. The analyses presented in this section are based on the anticipated reaction of the aquatic system to the impacts of specific development schemes proposed for the river. These schemes are treated herein in the following order: no development; Kekreti Storage Dam; Kekreti Storage Dam and Guinean Dams; Kekreti Storage Dam and Balingho Salinity Barrage; Kekreti Storage Dam, Guinean Dams, and Balingho Salinity Barrage.

Although development activities will result in alterations to many aspects of the physical, chemical, and biological aquatic environment, the economic repercussions of these activities will be reflected most obviously in changes to the fishery resources in the basin. Also, it is exceedingly diffi-

cult to place a direct monetary value on changes in salinity, nutrient concentrations, and plankton or macrophyte production. Rather, the economic impact of changes in these factors are reflected to some degree as changes in measurable factors such as fishery yield and value. In view of these considerations, this section will focus on the economics of basin fisheries in relation to anticipated environmental impacts.

Emphasis has been placed on evaluating the general scale, trends or patterns, and relationships (e.g., respective sizes or economic contributions) among the various fisheries. Considerable ranges exist for all values cited in this section. Part of this, particularly with respect to future predictions, is due to the fact that population parameters and stock estimates have never been determined for any target species (finfish or shellfish) in the Gambia River or adjoining marine coastal waters. Without these data, all predictions must be considered representative estimates not final values.

No Development

Assuming no anthropogenic impacts to the river system beyond those changes already in effect, e.g., fishing, point-source pollution through waste discharge and human activities, harvest of mangroves for firewood, etc., the existing fisheries should generally continue to experience current patterns and trends in biological and economic yield. Most analyses presented in this section are focused on fisheries in The Gambia. Shellfish fishing does not occur in the freshwater reaches of the river in Senegal and Guinea. Industrial finfish fisheries were not found on the river outside of The Gambia. Only limited data from 1984 (summarized in Josserand, 1984) were available on artisanal finfish catch in Senegal - most of the river lies

within the national park where fishing is prohibited. No data were available on artisanal fishing or catch on the Gambia River or its tributaries in Guinea.

<u>Finfish fisheries</u> -- Fishery Department statistics show a steady decline in the industrial fishery catch in The Gambia from 20,089 metric tons in 1978 to 7,377 metric tons in 1982. Projected catch for 1983 was about 7,500 metric tons. The primary economic value of these catches was derived from fishing fees and export taxes, because the fish were exported for sale outside the basin. Total receipts to the Gambia Government for these fish have declined from about 1 million dalasis in 1978 to 0.3 million dalasis in 1982.

A biological basis for the reported decline in industrial finfish catch was not identified, but rather it appears that the decline in annual catch was related to anthropogenic factors. These factors include a decrease in fishing effort because of increased fishing costs which are not offset by increased value of the product (mostly sardines). Also, Josserand (1984) noted that constraints in distribution and marketing of fish were limiting factors in the artisanal fisheries; the same may be true for the industrial fisheries. Finally, only one company (Seagull Cold Stores) has fished Gambian waters consistently since 1978. During this period, total fishing effort has fluctuated considerably with the entry and exit of several foreign firms on an irregular basis.

The prognosis for the industrial fishery from a biological standpoint is good. Stocks should be able to support fishing effort and annual cropping equal to that of 1978 or more as some species may be capable of sustaining even higher annual yields. This suggests that given proper investment and

management in the industrial sector, annual economic yield via fees and taxes could approach 1 to 2 million dalasis. If the Fish Marketing Company (FMC) is brought into existence and catches are sold locally, total annual economic yield might increase by several million dalasis, depending upon species caught, market value, and fishing costs.

In the absence of river development, annual catch and economic yield from the estuarine and freshwater artisanal fisheries are expected to continue at their presently depressed levels in relation to prior years. An apparent major cause for this condition is the continuing drought and reduced streamflows in the river, which have reduced primary and secondary aquatic production. The absence of annual floodplain inundation and resultant biological production have had disastrous effects on riverine fisheries in The Gambia. Without intervention, combined annual economic yield from the estuarine and freshwater riverine fisheries in The Gambia is not expected to exceed 3 to 4 million dalasis, and could become considerably lower if the drought and exodus of fishermen from the occupation continue.

With respect to riverine freshwater fisheries, one possible intervention that could significantly increase (by 10-20%) the annual economic yield from existing levels of harvest is reduction in fish loss (e.g., damage and spoilage) through better handling and processing techniques, and improved distribution and marketing networks. Such intervention would require relatively little capital investment and would not exert increased fishing pressure on stocks that are already suffering from changing environmental conditions that are adverse to reproduction, survival, and growth. The same is true for estuarine and marine coastal fisheries. But, for these fisheries,

increased fishing effort and harvest may also be appropriate, in addition to the interventions noted for the riverine freshwater fisheries.

Shellfish fisheries -- The most important industrial shellfish fishery in the estuary is that for the pink shrimp (*Penaeus duorarum*). Annual yield has fluctuated during recent years, but increased from 227 metric tons during July 1982-June 1983 to 412 metric tons during the same period, 1983-1984 (van Maren 1985). The economic value of shrimp exported by National Partnership Enterprises, Inc. (NPE) during the 1982-1983 year was estimated to lie between 2.0 and 3.8 million dalasis (Josserand 1984; van Maren 1985). The value of shrimp exported by NPE during the 1983-1984 year could approach 5 million dalasis. During the period July 1982- June 1983, the economic yield of this industry exceeded revenues collected from industrial finfish fishing and export taxes by a factor of 30. Preliminary evaluation of available data indicated that the economic value of the 1984 industrial export of shrimp approached one half that of the total value of artisanal fishing and exceeded receipts from industrial finfish fishing by 30-fold.

The foregoing figures underline the relative importance of the industrial shrimp export fishery to the local economy. Evidence indicates that shrimp stocks are presently not overfished. Caution must be exercised to allow migrating juvenile shrimp to exit the estuary during the onset of the annual floods, so that they can grow to maturity and spawn in the ocean, thus sustaining local shrimp stocks. This can be accomplished through the use of gear and mesh sizes which permit the escape of undersized shrimp. Van Maren (1985) stated that the coastal oceanic stocks of shrimp appear stable and capable of sustaining increased fishing pressure and annual yield. Given

these considerations, it can be expected that the annual economic yield of the industrial shrimp export fishery should continue at 3 to 5 million dalasis for the next few years.

The July 1982-June 1983 industrial export of mollusks and crustaceans (excluding shrimp) was 60.5 metric tons valued at about 123,000 dalasis (Josserand 1984). The stocks of all species exploited by these fisheries may be capable of sustaining considerable increases in fishing pressure and annual yield. Although industrial export of lobsters during the year listed above was 0.2 metric tons (valued at 1,300 dalasis), these stocks also appear to be underexploited in relation to sustainable yields. Josserand (1984) suggested that Gambian waters should sustain an annual yield of 1,000 metric tons of mollusks and crustaceans to the industrial fishing sector. The economic value of this catch could exceed 2 million dalasis, annually.

Within the artisanal shellfish fishing sector, the annual harvest of oysters and yeat (the marine snail *Symbium* spp.) contribute most significantly to the economic yield from this sector. The current annual harvest of oysters may approach 150 metric tons and be valued at 900,000 dalasis. Although these are approximate estimates of catch and value, the ranges shown are probably representative for the fisheries. Stocks of oysters and yeat could likely sustain increased levels of harvest. Market demand for these fish products, particularly for yeat, may be the major limiting factor with regard to expansion of these fisheries.

With respect to artisanal fishing for crustaceans, most shrimp and lobsters are sold to industrial processors. The economic return on catch of these species sold directly by artisanal fishermen on local markets is probably insignificant in comparison with that received from export sales of

these products. As noted previously, an unquantified but likely under-exploited fishery in marine and estuarine waters is that of crabs. The present economic yield on crab fishing is almost insignificant in comparison with other fisheries. But, the extent and economic value of crab fisheries for related species elsewhere in the world suggests further investigation into the potentials for expanding the crab fishery in Gambian waters is warranted.

All of the stocks of mollusks and crustaceans currently exploited by artisanal fisheries may be capable of sustaining considerable increases in annual harvest and economic yield. Outside of increased knowledge on the life history, distribution, and targeting of these stocks, the factors currently limiting the economic value of these fisheries appear to be more socioeconomic than biological in origin.

Kekreti Storage Dam

If construction activities and river alterations are limited to those proposed for the Kekreti Storage Dam, existing fisheries in The Gambia and Guinea will remain basically unaltered. Some redistribution of fishing effort (e.g., emigration of fishermen from riverine areas adjoining the reservoir) and marketing may occur, but riverine and coastal stocks in these countries should be generally unaffected by the reservoir. This assumes that the annual flood below the Kekreti Reservoir will not be altered grossly by the construction and operation of the dam.

An exception may be the narrow band or interface between the upstream boundary of the reservoir and the Guinean headwaters. Some ecological adjustment of existing riverine fish with the developing complement of lacustrine species associated with the reservoir can be expected. If

anything, the yield and economic value of fish taken from this portion of the river may increase with respect to existing levels. Because fishing is currently prohibited in much of the river immediately below the proposed dam site, any fish taken from this portion of the river following construction of the dam would represent an increase in catch and economic yield. However, this increase would be insignificant in relation to the economics of the fisheries elsewhere on the river or in the reservoir.

By far, the major economic effects of the Kekreti Storage Dam that will accrue directly from the aquatic system will stem from the colonization of the reservoir by lacustrine species of fish. These species will eventually comprise a spectrum of stocks available to whatever artisanal reservoir fishery develops in the region. The present yield and economic value of fish taken from the reach of the river that will be displaced by the reservoir, while of local importance, is almost insignificant in terms of basin-wide fishery economics. Those fishermen who presently rely on the riverine fishery could undoubtedly be supported by the developing reservoir fishery. An attempt has been made to place bounds on levels of biological and economic yield that can be expected from the reservoir fisheries as they develop.

Four methods were used to estimate annual yield from the reservoirs proposed for the Gambia River: (1) based on the artisanal fishery, (2) based on an established morphoedaphic index, (3) based on primary productivity rates and, (4) based on total phosphorus concentrations. Method 1 assumes that yield per hectare for the reservoir will at least equal that from the existing lower freshwater river. Methods 2 and 4 are based on factors that reflect the general nutrient content of the water and therefore its potential biological productivity. Values for these factors are those measured in the existing

river at the various dam sites. Method 3 extrapolates secondary production from primary production. The models used in methods 2-4 were developed using empirical data compiled during studies of rivers and reservoirs in Africa (see previous sections for discussion and application of these models and estimates to this project).

However, caution must be exercised when interpreting this or any other prediction presented in this section. The figures are calculations for yield and economic value based on existing-system catch statistics or empirical models developed from other aquatic systems. Each system, including the Gambia River, requires unique models. Such system-specific models usually will not yield highly accurate predictions when applied to other systems. Also, because catches predicted for the Gambian reservoirs are based on yields observed elsewhere in Africa, the figures do not indicate levels of biologically sustainable yield or optimum economic yield. Such estimates can only be generated through directed studies such as stock assessment, biological monitoring, and catch-assessment surveys conducted on the reservoir itself. Also, following initial colonization, most reservoirs show initially high levels of fish production which decrease and level off in subsequent years. This process takes about 15 years in temperate zones and less than 8 years in the tropics (personal communication, A. Beeton, University of Michigan). Therefore, in the long-term, annual biological and economic yield from the Kekreti Reservoir may be reduced from initial levels. Because the trophic age and stability are not known of the lakes and reservoirs from which the models used in this section to predict biological production were developed, fish production (yield) estimates presented herein may be higher than those actually realized over the life of the reservoir.

Estimates of catch and economic value predicted for the Kekreti Reservoir are summarized as follows:

- Method 1 - 2,176 metric tons valued between 652 and 870 million CFA;
- Method 2 - 1,488 metric tons valued between 446 and 595 million CFA;
- Method 3 - 131 metric tons valued between 94 and 125 million CFA;
- Method 4 - 28 metric tons valued between 8 and 11 million CFA.

For the Kekreti Reservoir, the estimates of total annual yield and economic value of fish range from 28 to 2,176 metric tons with respective values from 8 to 870 million CFA. The lower range represents estimates based on current nutrient concentrations and primary production in the river; evidence suggests that these will increase in the reservoir. Reservoir waters should be at least as productive as those of the existing river, and probably more so. Therefore, the upper end of these estimates is more representative of annual yield and economic value of fish production expected from the Kekreti Reservoir.

The estimated 2.7 to 3.7 million CFA annual worth of river-caught fish currently marketed in Kedougou, Senegal, is considerably less than the lower estimate of annual economic yield of 8 million CFA predicted for the Kekreti Reservoir. Thus, the Kekreti Reservoir has great potential to increase regional annual yield of fish and to stimulate the local economy through its production and economic yield. This presumes both the biological success of the reservoir as well as the implementation and support of fisheries development activities required to judiciously exploit the resources of the reservoir.

Kekreti Storage Dam and Guinean Dams

The existence and operation of the Guinean dams above the Kekreti Reservoir should have only minor economic impact on existing fisheries in the portion of the Gambia River west of Niokolo Koba Park. This assumes that the seasonal hydrological regime downstream from the Kekreti and Guinean dams will remain basically unaltered by construction and operation of the dams.

While the present catch and economic value of fish taken from the Guinean portion of the Gambia River and its tributaries are unquantified, they are undoubtedly small, particularly in comparison with the catch and economics of the river fisheries in Senegal and The Gambia. Therefore, the annual yield and economic value of fish predicted for the Guinean reservoirs may be simply added to that predicted for the Kekreti Reservoir and summarized as follows:

- Method 1 - no estimate (no catch statistics were available for Guinea);
- Method 2 - 476 metric tons valued between 143 and 190 million CFA;
- Method 3 - 93 metric tons valued between 28 and 37 million CFA;
- Method 4 - no estimate (total phosphorus was not measured for Guinean waters of the river).

These figures indicate that the annual yield of fish from the Guinean reservoirs could range from 93 to 476 metric tons valued at 28 to 190 million CFA. If these numbers for catch and value are added to those predicted for the Kekreti Reservoir, the predicted annual yield from the 4-reservoir system ranges from 121 to 2,652 metric tons. The value of this yield ranges from 36 to 1,060 million CFA. Because these figures represent the additive effects of wide-ranging estimates, the combined range is very large. However, the upper and lower values for these ranges are probably realistic limits which can be expected from this reservoir system. For reasons discussed previously, actual

catch and economic value realized from the 4-reservoir system will likely approach the upper end of the estimated range of values, rather than the lower end of these predictions.

Kekreti Storage Dam and Balingho Salinity Barrage

The addition of the Balingho salinity barrage to the Kekreti storage dam will have profound and far-reaching effects on all riverine fisheries below the headwaters region in Guinea. By far, the greatest proportion of the impact of this development scenario on the economic resources of the aquatic system will be contributed by the addition of the Balingho salinity barrage to the basin development scheme.

The biological impacts and economic implications of the Kekreti Reservoir were discussed above. The addition of the Balingho salinity barrage to the river system should not significantly affect the biology, production, and economics of the Kekreti Reservoir fisheries. This assumes that the manpower and economic assistance required to develop the Kekreti fisheries will not be reduced by the addition of the Balingho salinity barrage to the development scheme. But, because the human and economic resources available to develop new impoundment fisheries are limited, the addition of the Balingho salinity barrage and development of its fisheries will probably reduce the rate of development and economic yield that would be realized from the Kekreti Reservoir in the absence of the Balingho salinity barrage. Because figures are not available on levels of manpower and economy committed to fishery development in the basin, the extent of this reduction in Kekreti fisheries development and economic yield cannot be estimated with accuracy at this time.

The Balingho salinity barrage will have several major effects on fishery biology and economics in the Gambian portion of the river and adjoining coastal waters. First, the impoundment upstream of the barrage will permit development of a freshwater reservoir fishery, but the existing riverine finfish fishery will be eliminated within, and to some extent above, the impoundment, as will all shellfish fishing. Second, all existing fisheries for estuarine species of finfish and shellfish upstream from the barrage site will be permanently eliminated. Additionally, fisheries for species (e.g., bonga, shrimp, crabs) which require estuarine conditions to complete portions of their life cycles will be severely affected, and local populations of these species will be reduced to varying extents. Finally, the vast bulk (80 to 90%) of the annual organic input to the lower-freshwater and estuarine reaches of the river as well as adjoining coastal waters comes from the floodplains, bolons, and mangroves. All of these habitats and their contribution to total production will be lost to the aquatic system above the barrage. Below the barrage, floodplain habitat will be eliminated if no water is released from the river, mangroves will be eliminated in areas of hypersaline water, mangrove forests will undergo major shifts in species composition for about 30 km downstream of the barrage, and inland reaches of existing bolons will disappear. All of these conditions will reduce downstream riverine production dependent on nutrient inputs from these sources.

Predictions of the annual yield of finfish from the reservoir created by the Balingho salinity barrage range from 68 to 6,325 metric tons with an economic value between 0.1 and 9.5 million dalasis, based on present market prices (Josserand 1984) for freshwater species expected to colonize the impoundment. The larger figure for each estimate was developed using Method 1

which assumed that yield per hectare for the impoundment would equal that of the existing river as determined from catch-assessment data.

But before the above estimates for the Balingho Reservoir can be added to those of the Kekreti Reservoir, it is necessary to consider losses and gains to existing fisheries in the area that will be affected by the Balingho barrage. The total net loss or gain to these affected fisheries must be added (or subtracted) from the values predicted for the Balingho Reservoir itself. Then, it will be possible to estimate the total ultimate yield and economic value from the Kekreti-Balingho impoundment system.

Industrial finfish fishing does not currently occur above Balingho, but the catch of the freshwater river (Upper River Division) artisanal fishery in The Gambia is valued at about 1 million dalasis, annually. Most of this fishery and its revenues will be replaced by the reservoir and whatever fisheries develop in association with it.

Shrimp, oysters, crabs, and perhaps some lobsters are caught at present in areas above the barrage site and contribute to the total annual economic value of these products. Summarized for Gambian waters, these totals are: shrimp - 5 million dalasis, oysters - 0.9 million dalasis, and lobsters and crabs - 0.001 million dalasis. The combined total annual value of these shellfish products is about 6 million dalasis. The economic yield of the lobster and crab fishery is almost insignificant with respect to the others. At least one half (0.5 million dalasis) of the annual oyster harvest occurs in downstream areas of the hydrological regime which will be relatively unaffected by the barrage. The proportion of the shrimp catch that is taken above the barrage site is not known but probably comprises no more that 10% of the total annual harvest. These figures suggest that the total reduction in

existing shellfish production and economic yield would be about 0.6 million dalasis, annually, by virtue of the reservoir.

However, several additional factors must be considered which could greatly increase losses to these shellfish fisheries. First, all of these organisms have one or more lifestages that feed on suspended or benthic organic material, much of which is transported down the river from a variety of sources, e.g., floodplains and mangroves. Unless a large volume of water is allowed to pass through the barrage, that downstream transport will be greatly reduced. The result will be a significant change in the composition of prey species and detrital material available to these shellfishes, as well as an overall reduction in the amount of their food present in the water. This dietary shift and overall reduction in food supply to shrimp, oysters, lobsters and crabs may have much more far-reaching and adverse effects on local stocks of these species than the changes in the hydrological regime.

An additional consideration regarding the effect of the Balingho salinity barrage on shellfish populations below the barrage site is that some organisms require the presence of brackish water to complete their life cycles. This appears to be the case for the juvenile stage of the penaeid shrimp stocks fished in estuarine waters of The Gambia (van Maren 1985). Whether or not marine coastal stocks of shrimp that do not require brackish water exist in Gambian waters remains unknown.

In view of the above considerations, the potential reduction in shellfish stocks and economic losses could easily exceed 50% of the annual total. The worst case scenario is that all of these fisheries would collapse, resulting in a 6 million dalasis loss to the local economy. Whatever the

figure (3 to 6 million dalasis), it must be subtracted from any economic gain resulting from Balingho Reservoir fisheries.

An additional economic impact of the Balingho salinity barrage that must be evaluated prior to estimating the total yield and economic value of the Kekreti-Balingho impoundment system is the potential effect of the Balingho salinity barrage on finfish fisheries downstream from the barrage. Sardines comprise the bulk of the annual industrial finfish catch which has been valued at about 0.5 million dalasis. This fishery is confined to marine coastal waters and should remain relatively unaffected by the barrage, although the diet and dependence of these sardines on suspended organic material discharged from the river into the ocean has not been, but should be, established. With respect to artisanal finfish fishing, the marine coastal catch is valued at about 12 million dalasis, and the estuarine river catch (i.e., the Lower River Division) at about 1 million dalasis, annually.

Both the marine-coastal and in particular the estuarine artisanal fisheries depend on species of fish, e.g., bonga (Ethmalosa fimbriata) and catfishes, which either require or prefer brackish water during some stage in their life cycle. Detailed description of major fish species in the Gambia River including their habitat requirements for spawning, nursery areas, and feeding was presented in previous sections of this report.

It is expected that marine coastal stocks of bonga (and the associated fishery for these stocks) will suffer less from river basin development than will the estuarine stocks and fishery on the river. This is believed to be the case because bonga use both estuarine and marine environments for spawning and nursery areas. Also, stocks of bonga (and associated fisheries) which exist at the extreme north and south ends of the Gambian coastline are

probably outside of the direct influence of the river. Marine coastal conditions and estuaries north and south of the Gambia River, upon which these fish are dependent, should remain relatively free from impacts of basinal development.

However, potential long-term effects of river impoundments on the Atlantic coastal stocks and fisheries for bonga (and other aquatic organisms for that matter) must not be underestimated. Although individual development projects may have relatively localized or isolated effects on the bonga, the combined impact of several development projects within the region (e.g., Senegal River, Gambia River, Casamance River) may become significant over time. An equally critical concern is the extent to which estuarine and marine stocks of bonga are segregated (or intermix) during spawning and at other times during their life cycle. The GRBS provided a clear evaluation of the abundance, distribution, life history, movements, and spawning of riverine bonga, but not of oceanic fish. However, the relationship between estuarine- and ocean-dwelling bonga needs to be explored.

About 60% of the 1981 marine coastal artisanal fishery catch was comprised of species that also inhabit the lower estuary. Direct effects of the barrage on the coastal stocks of these species will be minimal. The remaining 40% of the 1981 catch was comprised of fish (e.g., bonga, mullet, jortoh) also occurring in the upper and lower estuaries at all stages in their life history. These species inhabit both estuarine and marine environments, although as noted for bonga, the extent of their dependency on estuarine conditions is not fully understood.

Given the preceding considerations, less than a 10% annual reduction in catch (valued at 1.2 million dalasis) is expected in the artisanal marine

coastal fishery sector as a result of the barrage. Also, the initial reduction might be offset over time by the reallocation of fishing effort toward other target species.

The artisanal estuarine (Lower River Division) finfish fishery has been valued at about 1 million dalasis annually. Bonga comprised 22% by weight of the total 1981 catch from this fishing sector, but a smaller proportion of the total economic value because the market value (0.5 dalasis/kg) of bonga is considerably less than that for other species (average price = 2.3 dalasis/kg, based on prices as cited in Josserand 1984). Other fish species that may require estuarine conditions and are caught by this fishing sector made up less than 10% by weight of the remainder of the 1981 catch. Given the total elimination of bonga and other estuarine fish species by the Balingho Reservoir and dam, the estuarine catch should experience about a 30% reduction in catch by weight; in terms of economic value the reduction will be even less. This would amount to an annual loss of about 0.3 million dalasis to this fishery based on 1981 landings and prices cited above. In practice, total elimination of these species from the residual fishery is unlikely.

Predicted annual losses to existing fisheries from effects of the barrage can be summarized from the preceding discussion as follows: freshwater artisanal finfish fishery above the barrage - 1 million dalasis, shellfish fishery above and below the barrage - 3 to 6 million dalasis, estuarine artisanal finfish fishery below the barrage - 0.3 million dalasis, marine coastal artisanal fishery - 1.2 million dalasis, and the industrial finfish fishery - insignificant losses. The combined total of these annual economic losses estimated for existing fisheries is 5.5 to 8.5 million dalasis.

Predictions have not been offered regarding the extent to which targeting and catch of alternate stocks would offset losses to existing fish stocks. This process would undoubtedly compensate varying losses in all fisheries. Also, populations of some existing species might increase with the reduction or elimination of competitors affected by the barrage, thereby permitting increased levels of exploitation for these species.

The predicted annual economic yield for the Balingho Reservoir ranged from 0.1 to 9.5 million dalasis, depending on the model used. This yield must be balanced against predicted losses to existing fisheries resulting from effects of the barrage. These losses have been estimated to range from 5.5 to 8.5 million dalasis, annually. The above estimates suggest that, with respect to fishery economics, the maximum annual economic gain that can be realized from the Balingho Reservoir is 4 million dalasis. This figure assumes maximum levels of reservoir yield and minimum losses to existing fisheries, an improbable circumstance. If the converse assumptions are made, a net loss of 8.4 million dalasis could be realized.

Values for annual fisheries catch and economic yield predicted for the Kekreti and Balingho reservoirs combined are (assuming 10 dalasis = 1,000 CFA):

- Method 1 - 8,501 metric tons valued between 662 and 910 million CFA;
- Method 2 - 7,169 metric tons valued between 446 and 540 million CFA;
- Method 3 - 1,122 metric tons valued between 21 and 82 million CFA;
- Method 4 - 96 metric tons with a net loss of 44 to 77 million CFA to the system.

The potential annual yield estimated for this two-impoundment system ranges from 96 to 8,501 metric tons. When losses expected to existing

fisheries are included, the total economic value of this yield ranges from a net gain of 910 million CFA to a loss of 77 million CFA annually. The wide range in these estimates results from the lack of information on the feasibility (biologically and economically) of exploiting the reservoir fisheries to their maximum while maintaining losses to existing fisheries at minimum levels; best- and worst-case scenarios have been presented. In actuality, the yield by weight and economic value realized from the Kekreti-Balingho impoundment system will probably fall in the upper range of figures cited above. But in terms of aquatic ecology, fisheries, and economics the addition of the Balingho salinity barrage to the basin development scheme is a risky investment at best, and at worst could result in serious ecological damage and economic losses to the system.

Kekreti Storage Dam, Guinean Dams, and Balingho Salinity Barrage

The addition of the Guinean dams to the Kekreti-Balingho impoundment system will have little effect on the fisheries and economy in these lower reservoirs. The major economic impact will be the addition of the annual yield and economic contribution of the Guinean dams to the total yield and value of post-development fisheries in the basin. As before, this assumes that adequate manpower and economic assistance will be available to develop the Guinean component without subsequently reducing resources available to develop the fisheries and aquatic resources of the Kekreti and Balingho Reservoirs.

If the figures for yield and economic value predicted for all five impoundment are summed, the following totals are obtained:

. Method 1 - no estimate (no catch statistics were available for Guinea);

- Method 2 - 7,645 metric tons valued between 589 and 731 million CFA;
- Method 3 - 1,215 metric tons valued between 49 and 119 million CFA;
- Method 4 - no estimate (total phosphorus was not measured for Guinean waters of the river).

Because both the manpower and economic assistance available to develop the potential reservoir fisheries as well as those already in existence are limited, the rate of increase toward maximum economic yield from the individual reservoir fisheries will be slowed as additional projects are brought into the development plan. If development resources and assistance are highly limited, total economic yield from the 5-impoundment system will be less than yields obtainable from a smaller but more highly developed, exploited, and managed complex of impoundments.

GENERAL DISCUSSION

FISH ECOLOGY

This section summarizes the major findings on three aspects of fish ecology in the Gambia River: abundance and distribution of fish in relation to habitat type, the effect of selected physical and chemical parameters on fish distribution, and categorization of fish into major trophic groups based on diet inferred from the analysis of stomach contents of fish sampled during the study.

In general, fish inhabiting the pelagic region of the lower reaches of the river tended to occur in schools rather than as solitary individuals. This observation was supported by the predominance of schooling fish (e.g., *Ethmalosa*, *Fonticulus*, *Sardinella*) in pelagic gill nets and trawls, as well as the use of surround nets by artisanal fishermen fishing the offshore pelagic regions of the lower river and upper estuary. Solitary fish (e.g., sharks and other large piscivorous fish) were more common in the lower estuary which was in many respects more typical of open coastal waters than of the distinctly channelized sections of the river above the lower estuary.

In the lower river and upper estuary reaches of the river, the main channel bottom is flat and smooth which offers fish little protection from current or predators. The banks are nearly vertical or undercut and interlaced with roots, particularly in the estuarine portions of the river which support fringing mangroves. In general, non-schooling fish, particularly catfish, tended to remain close to the river banks rather than the bottom in the central portions of the main channel. Gill nets set on the surface or on the bottom within 1-3 m of the river banks generally caught more fish than nets set in similar strata in the main channel of the river. This general

pattern was particularly evident in the lower river and upper estuary where tidal currents were strong and the river banks were nearly vertical. However, a similar tendency for fish to congregate near the river banks was noted in the upper river, particularly during the high water stages.

Artisanal fishermen used gill nets and long lines almost exclusively adjacent to the river banks. Rarely were these gear observed to be deployed in the central regions of the main channel. Often, surface gill nets were allowed to drift with the current parallel to, and 2-3 m from, the banks of the river. As the nets drifted, the fishermen slapped the surface of the water to drive fish residing in the roots and vegetation along the river banks out into the net.

Measurement of the abundance or standing stock of fish in the bolons clearly showed that fish concentrated in the bolons. Fish densities (kg/hm^2) were much higher in the bolons than on the floodplains or in the main river channel. The primary reasons for this were probably the increased protection that the bolons offered combined with perhaps a more concentrated input of organic material (e.g., detritus, insects, seeds, etc.) that serves as food for fish.

Sampling on the floodplains revealed a near absence of fish from most areas. The primary reason for the paucity of fish in this habitat was the drought and low water levels that resulted in the nearly total draining of most floodplain areas during low tide. This draining required the fish to migrate in and out of the area twice a day, thus establishing a predictable but very unstable habitat for fish.

Multiple correlation analysis was conducted between the index of abundance (CPE for standard series gill nets) of ten major fish species and

selected physical and chemical parameters that were measured in conjunction with fish sampling (Table 28). The absolute value of the correlation coefficient between CPE and salinity ranged from 0.4 to 0.7 for all species except one, although both positive and negative correlations occurred. The absence or presence of saline water strongly affected the distribution of these fish species, and was a good indicator in terms of predicting the general distribution (absence or presence) of these species in the various river zones.

Positive correlations between CPE (catch per effort) and salinity were noted for the following species: Sardinella maderensis - 0.4, Ethmalosa fimbriata - 0.7, Ilisha africana - 0.7, Arius latiscutatus - 0.8, and Arius heudeloti - 0.7. These species required saline water and were rarely captured in fresh water. These fish formed a major component of the halophilic species complex.

Negative correlations between CPE and salinity were noted for the following species: Schilbe mystus - 0.5, Chrysichthys nigrodigitatus - 0.4, Fonticulus elongatus - 0.3, Synodontis gambiensis - 0.7, and Pellonula vorax - 0.7. Most of these species were captured mainly in fresh water, and formed a major component of the halophobic fish complex. Fonticulus elongatus were collected from both estuarine zones and the lower river zone; this mesohaline species showed a wide distribution throughout the lower reaches of the river and a tolerance for both saline and fresh water.

The results of correlation analysis between CPE and the other physical and chemical parameters were difficult to interpret. In some instances, strong correlations existed between variables (e.g., salinity and conductivity). In other cases (e.g., nutrients - silica, phosphorus), gradients existed along the reach of the river, and correlations between CPE and these fac-

TABLE 28. Physical, chemical, and biological factors examined for effects on abundance and distribution of major species of fish in the Gambia River, West Africa, 1983-1984.

Factor	Unit of measurement
Physical	
Water temperature	degrees C
Conductivity	μmhos/cm
Salinity	mg/L
Suspended solids	mg/L
Chemical	
pH	standard units
Alkalinity	mgCaCo^3/L
Dissolved oxygen	mg/L
Dissolved oxygen	% saturation
Soluble reactive silica	mg/L
Soluble reactive phosphorus	μg/L
Total phosphorus	μg/L
Nitrate-nitrogen	μg/L
Total nitrogen	μg/L
Biological	
Chlorophyll *a*	μg/L
Phaeo-pigments	μg/L
Primary productivity	μg C/L/h
Attached bacteria	millions/mL
Free bacteria	millions/mL
Heterotrophic uptake	μg/L/h
Phytoplankton	no./m^3
Zooplankton	no./m^3
Invertebrates	relative abundance (%)
Larval fish[1]	no./1,000 m^3

[1] Comparisons of larval and adult fish abundance were made among related (e.g., species, genus, family) taxa.

tors occurred but were not necessarily meaningful or valuable in predicting the absence or presence of a given species.

The results of analysis of stomach contents conducted on samples of the major fish species, discussed earlier, led to the classification of fish into four general groups according to Odum et al. (1982): detritivores, mixed trophic level feeders, middle carnivores, and higher carnivores. Detritivores fed almost exclusively on organic detritus. Food items found in the stomach of mixed trophic level feeders included: detritus, seeds and grains, vascular plants, insects, clams and snails, shrimps, crabs, and fish. Middle carnivores fed primarily on insects, mollusks, shrimps, and crabs. Higher carnivores fed almost exclusively on fish.

Twilley (1985) summarized and discussed the results of stomach content analyses conducted on fish sampled in a bolon near Bai Tenda, The Gambia. Detritivores included: *Tilapia* sp., *Liza falcipinnis*, *Tilapia occidentalis*, *Pellonula vorax*, and *Tilapia heudeloti*. Mixed trophic level feeders included: *Chrysichthys nigrodigitatus*, *Chrysichthys furcatus*, *Fonticulus elongatus*, *Pythonichthys marcrurus*, and *Psettias sebae*. Middle carnivores included: *Plectorhynchus macrolepis*, *Polydactylus quadrifilis*, *Elops senegalensis*, *Schilbe mystus*, and *Bostrychus africanus*. Higher carnivores included: *Hemichromis bimaculatus*, *Hemichromis fasciatus*, *Hepsetus odoe*, *Strongylura senegalensis*, and *Hydrocynus brevis*.

The results of our studies in the Gambia River support the general concept of the river as a sluice for organic material, about 85% of which comes from allochthonous inputs from mangrove forests which serve as a sink for nitrate, phosphate, suspended solids, and vascular plant litter (Twilley 1985). The result is a fish species complex in the estuarine reaches of the

river that is dominated by detritivores. The above-named species sampled in the bolon comprised about 50% of the artisanal fishery catch between Banjul and Kaur, The Gambia (near the upper end of the estuarine portion of the river) in 1983. In the lower river zone from Kaur to Fatuto, The Gambia, about 30% of the annual artisanal catch is comprised of Tilapia, which is a detritivore found throughout the length of the Gambia River.

Our sampling, analysis of stomach contents, and the artisanal fishery catch all indicate a fish species complex that is dominated by detritivores, especially in the river reaches below the headwaters. This observation helps to explain the concentration of fish near the river banks and in the bolons. Most likely, because the bulk of organic detrital input enters the river from its banks or the bolons, the fish are concentrating where both shelter and a more concentrated food supply are available. The rain of seeds, vascular plant material, and insects into the river is undoubtedly highest along the banks of the river and in the bolons where these materials drain off the floodplains.

The proposed barrage at Balingho would have major impacts on the ecology of fish in terms of the habitat, salinity, and alteration of the food chain. The formation of an impoundment above the barrage would eliminate the existing main channel, river bank, and bolon system that presently determines the distribution of fish in terms of habitat requirements. In general, pelagic habitat will increase and the fringing river bank and bolon habitat will greatly diminish. Because the physical and chemical environment will be drastically altered by the barrage, it is difficult to isolate, a priori, those species that will increase or decrease in numbers strictly from changes in the type and distribution of habitat. However, habitat alteration will

combine with other effects of the barrage to greatly impact the abundance and distribution of fish in the lower river and upper estuary zones.

The proposed barrage will also dramatically alter the physical and chemical features of the existing environment in the lower river and upper estuary zones in the vicinity of the barrage. Above the barrage, halophilic species (including those discussed above) will be eliminated. Below the barrage, only fish species that can tolerate salinities approaching or exceeding those of marine waters (35 ppt) will survive. All halophilic species (including those indicated above) will be eliminated below the barrage. Changes in other physical and chemical factors resulting from the barrage will also have a profound impact on the abundance and distribution of fish, existing fish species complexes, and the associated fisheries above and below the barrage site.

The salinity barrage will result in a major loss of mangroves and a decline in detrital input equal to 82% of the organic matter input to the estuary (Twilley 1985). The loss of this detritus will greatly reduce the numbers of detritivores and severely impact the existing detritus-based artisanal fishery in the lower river and estuarine zones.

Changes in habitat, the chemical and physical composition of the water, and the food chain resulting from the presence and operation of the proposed barrage at Balingho will have a profound impact on the abundance and distribution of fish in the lower river and upper estuary zones. A complete restructuring of the species complexes in these reaches of the river can be expected. Concurrent with these shifts in the population structure of fish inhabiting these zones, large shifts in the artisanal fishery catch will also occur in terms of both types and numbers of fish caught. This will require targeting of different species, use of alternate gear and catch techniques,

and changes in the marketing and consumption of fish consumed locally or exported from these regions of the river.

FISH PRODUCTION

Prior to this discussion, the following working definitions are offered for the terms fish stock, standing crop, annual production, annual yield, and sustainable yield. A stock is an identified group of one or more species of fish which comprise the target of fishing efforts. The fish may be vulnerable to capture at one or more stages in their life history. Standing stock (also called standing crop or usable stock) is the number or weight per given area or water volume of all fish in an identified group which are available for use (i.e., can physically and legally be caught). Production is the total elaboration of tissue within a specified period of time (e.g., annual production = total elaboration during a 1-yr period). Annual yield is the biomass of fish that is available to a fishery. It is defined, in part, by gear deployed and lifestage or size of fish targeted. Equilibrium yield (also called surplus production, equilibrium catch or yield, and natural increase) is the weight of fish taken from a stock when it is in equilibrium with fishing of a given intensity. Apart from naturally-induced variation, the biomass of the stock does not change over time as a result of fishing mortality.

Three factors must be considered when evaluating the fishable biomass of a stock: the total amount of ichthyomass present at a given place and time, the total amount of tissue elaboration or increase in fish biomass per unit time, and the fraction of that biomass which can be harvested on a sustained basis without eventually reducing total production.

Standing Stocks

Main Channel--

Pelagic and benthic trawls provided our only direct estimates of standing stock in the main channel of the Gambia River. Also, sampling was limited to the lower river, upper estuary, and lower estuary zones where trawling could be conducted with the R/V *Laurentian*. Pelagic trawls were assumed to sample fish in the upper three quarters (quadrats) of the water column, while benthic trawls sampled fish within 1 m of the bottom. The 4.8 m (headrope) otter trawl was towed at a speed of 4.8 km/h (3 mph) for 10 minutes. The total area fished was about 3,840 m^2 or 38.4 hm^2 (hundred square meters). The total weight of fish caught in each separate trawl was calculated and expressed as kg/hm^2 (Table 29).

The standing stocks estimated from pelagic trawl samples were extremely small, never exceeding 0.2 kg/hm^2, and usually much less. These biomass estimates were undoubtedly only a fraction of the total standing stock contained in the areas fished. Several factors accounted for these low estimates. The trawl net was designed to assess the diversity of fish species rather than the total biomass in an area. The area fished was much too small given the highly uneven distribution of fish. Also, schooling fish and large, fast-swimming individuals, which comprise a large portion of the standing stock, were not vulnerable to the gear. In fact, the largest estimates of standing stock were achieved when some schools of fish (e.g., *Sardinella maderensis*, *Ethmalosa fimbriata*, *Ilisha africana*, *Fonticulus elongatus*) were encountered and trawled.

Slightly larger catches (and estimates of standing stock) were attained from the benthic trawls (Table 30). This was probably an effect of increased

TABLE 29. Standing stock of fish determined from pelagic trawls made in the lower river and upper and lower estuaries of the Gambia River, West Africa, 1983-1984.

Ecological zone	River stage	Date	Time	kg of fish	kg/hm^2
Lower river	Low water	9 Mar 84	1930	0.104	0.003
			1945	0.052	0.001
		10 Mar 84	0830	0.008	<0.001
			0855	0.616	0.016
Upper estuary	Peak flood	9 Oct 83	1420	0.029	<0.001
			1500	0.059	0.002
			1520	0.028	<0.001
	Low water	6 Mar 84	1650	0.113	0.003
Lower estuary	Declining water	8 Nov 83	1400	0.092	0.002
			1415	0.153	0.004
			2035	0.346	0.009
			2050	0.011	<0.001
	Low water	31 Mar 84	1245	1.187	0.031
			1300	2.823	0.074
			1410	0.155	0.004
			1430	1.125	0.029
			2015	0.716	0.019
			2035	0.454	0.012
		21 Feb 84	1935	0.352	0.009
			2005	0.231	0.006
		22 Feb 84	1535	0.413	0.011

TABLE 30. Standing stock of fish determined from benthic trawls made in the lower river and upper and lower estuaries of the Gambia River, West Africa, 1983-1984.

Ecological zone	River stage	Date	Time	kg of fish	kg/hm^2
Lower river	Peak flood	2 Jul 83	1445	0.334	0.009
			1505	0.455	0.012
	Low water	9 Mar 84	2015	0.630	0.016
			2030	0.084	0.002
		10 Mar 84	0758	0.360	0.009
			0820	0.728	0.012
Upper estuary	Rising water	30 Jul 83	1815	3.714	0.097
			1835	0.667	0.017
			1850	0.021	<0.001
	Peak flood	9 Oct 83	1400	0.964	0.025
			1420	0.017	<0.001
			1540	1.508	0.039
	Declining water	8 Dec 83	1510	0.524	0.014
			1530	0.211	0.005
			1545	0.976	0.026
	Low water	6 Mar 84	1607	0.374	0.010
			1630	0.605	0.016
Lower estuary	Rising water	2 Aug 83	1257	0.203	0.005
			1315	0.466	0.012
			1628	1.636	0.043
			1725	0.358	0.009
			1745	2.934	0.076
			1925	0.149	0.004
		3 Aug 83	0045	0.036	<0.001
			0102	0.053	0.001
			0145	0.036	<0.001
			0200	0.043	<0.001
			0300	0.541	0.014
			0320	0.097	0.003
			0355	0.093	0.003
			0415	0.987	0.026
			1950	4.759	0.124
			2010	1.062	0.028
			2105	0.035	<0.001
			2125	0.075	0.002

(continued)

TABLE 30 (continued).

Ecological zone	River stage	Date	Time	kg of fish	kg/hm^2
		4 Aug 83	1035	0.251	0.007
			1055	1.066	0.028
			1205	3.933	0.102
			1227	1.597	0.042
			1315	5.501	0.143
			1335	7.664	0.200
	Declining water	8 Nov 83	1245	0.114	0.003
			1300	0.147	0.004
			1320	0.351	0.009
			1335	0.304	0.008
			1435	2.037	0.053
			1450	2.054	0.053
			1920	0.091	0.002
			1935	0.055	0.001
			1950	0.775	0.020
			2005	0.380	0.010
			2110	1.341	0.035
			2125	1.886	0.049
		15 Dec 83	1545	0.884	0.023
	Low water	31 Jan 84	1325	0.958	0.025
			1340	0.964	0.025
			1505	1.723	0.045
			1940	1.485	0.039
			2000	1.762	0.046
			2105	4.646	0.121
			2125	0.409	0.011
		21 Feb 84	1950	0.640	0.017
			2020	1.192	0.031
		22 Feb 84	1520	0.882	0.023
			1550	1.721	0.045

catch efficiency of the trawl resulting from a reduction in the ability of fish to avoid the net when it was towed on bottom. No indication of increased catches at night was noted. The water was usually very turbid (Secchi disc readings were usually less than 0.5 m), and the trawl was probably not much more visible during the day than at night.

Catches and estimated standing stocks were highest in the lower estuary, which was undoubtedly the most productive area with respect to fish. A similar pattern was noted for the standard series gillnet catches.

Bolon/Mangrove Complex --

A bolon located in the upper estuary near Bai Tenda, The Gambia, was sampled on 12-13 October 1983 during the peak flood and again on 5 March 1984 during the low water stage. The bolon drained a floodplain. The lower end of the bolon was closed off with a 0.63-cm (0.25-in.) bar mesh net at slack high tide. Rotenone was applied to 1,000 m of the bolon above the blocking net. Poisoned fish were collected in dip nets or trapped in the blocking net as the water drained out of the bolon during low tide. This procedure was repeated on 2 consecutive days (12-13 October 1983) to obtain a measure of the rate of replacement of fish in the bolon immediately following the initial poisoning. Sampling was conducted during the peak flood and low water stages to permit comparison of catch during the seasonal extremes of the river stages.
The bolon was about 10 m in width, therefore the total area sampled was 10,000 m^2. The water did not drain completely from the bolon and some fish sank to the bottom and were not collected. We estimated that at least 50% of the total number of fish poisoned were not collected. However, this biomass was not included in our summary data on fish catch.

Fish catches and standing stocks in the bolon ranged from 0.129 to 0.239 kg/hm^2 (Table 31). If those fish that were missed during sample collection were included the standing stocks might have been double or triple those cited in Table 31. Standing stocks of fish were similar for both high and lower water stages of the river. Interestingly, the standing stock of fish sampled on the second day (13 October 1983) of the 2-day consecutive sampling regime was about twice that sampled during the preceding day (12 October 1983). This suggests that the fish populations in the bolons are highly mobile and comprised of transient fish that migrate in and out of the bolons. Gill nets set across the bolons indicated considerable migration of fish out of the bolons during ebb tide and into the bolons during incoming tide. Artisanal fishermen were often observed to set gill nets across the mouths of the bolons.

For all samplings, Chrysichthys nigrodigitatus comprised nearly one half of the catch in terms of numbers and biomass. As described in the section which discussed fish ecology, C. nigrodigitatus is classified as a mixed trophic level feeder, and feeds on a wide variety of items. The runoff of a wide variety of organic material (detritus, seeds and grains, vascular plant material, insects) from the floodplain, combined with the extensive habitat provided by the mangrove root system and bolon channel banks to support invertebrates (clams, snails, crabs, fish) would favor fish species that were opportunistic in their feeding and which would accept a wide range of prey types. Therefore, it is not surprising that the fish population in the bolon was dominated by a mixed trophic level species. However, detritivores and middle and higher carnivores were also included in all three samplings of the bolon.

TABLE 31. Standing stock of fish sampled from a 10,000 m^2 area of a bolon in the Gambia River near Bia Tenda, The Gambia, 1983-1984.

Date	Time	Taxon	Number of fish	Weight (kg)
12 Oct 83	1030	Chrysichthys nigrodigitatus	110	3.823
		Hepsetus odoe	8	2.779
		Hemichromis bimaculatus	10	1.436
		Psettias sebae	18	1.122
		Hydrocynus brevis	2	0.947
		Chrysichthys furcatus	10	0.820
		Polydactylus quadrifilis	2	0.680
		Plectorhynchus macrolepis	1	0.402
		Liza falcipinnis	3	0.221
		Ethmalosa fimbriata	2	0.166
		Synodontis gambiensis	1	0.154
		Bostrychus africanus	2	0.100
		Hemichromis fasciatus	3	0.094
		Tilapia occidentalis	1	0.035
		Pythonichthys marcrurus	1	0.035
		Pellonula vorax	4	0.022
		Porogobius schlegeli	4	0.004
		Total	182	12.865
		Ichthyomass (kg/hm^2)		0.129
13 Oct 83	0900	Chrysichthys nigrodigitatus	414	12.613
		Psettias sebae	38	2.244
		Chrysichthys furcatus	15	1.640
		Fonticulus elongatus	18	1.632
		Polydactylus quadrifilis	5	1.391
		Liza falcipinnis	23	1.289
		Hepsetus odoe	3	0.740
		Hemichromis fasciatus	6	0.466
		Tilapia occidentalis	6	0.455
		Hydrocynus brevis	1	0.370
		Bostrychus africanus	15	0.218
		Pythonichthys marcrurus	9	0.208
		Porogobius schlegeli	146	0.168
		Tilapia rheophila	1	0.167
		Strongylura senegalensis	12	0.083
		Pellonula vorax	129	0.070
		Tilapia brevimanus	1	0.048
		Elops lacerta	2	0.047
		Aplocheilichthys normani	35	0.028
		Cynoglossus senegalensis	9	0.019
		Elops senegalensis	1	0.018
		Hemichromis bimaculatus	1	0.018
		Schilbe mystus	10	0.017
		Total	900	23.949
		Ichthyomass (kg/hm^2)		0.239

(continued)

TABLE 31. (continued).

Date	Time	Taxon	Number of fish	Weight (kg)
5 Mar 84	0915	*Chrysichthys nigrodigitatus*	140	7.345
		Tilapia heudeloti	33	2.654
		Hepsetus odoe	7	2.623
		Liza falcipinnis	70	2.532
		Chrysichthys furcatus	31	2.398
		Hemichromis fasciatus	14	0.709
		Tilapia spp.	3	0.652
		Elops lacerta	3	0.086
		Bostrychus africanus	2	0.060
		Pellonula vorax	10	0.030
		Ethmalosa fimbriata	1	0.028
		Strongylura senegalensis	1	0.020
		Pomadasys jubelini	1	0.015
		Cynoglossus senegalensis	7	0.003
		Porogobius schlegli	5	0.003
		Total	328	19.158
		Ichthyomass (kg/hm^2)		0.192

The diversity of fish species in the bolon was slightly higher during the peak flood when 17 and 23 species were collected than during low water when 15 species were collected. The species composition during the three sampling periods was similar, but the relative proportions or abundance of a given fish species varied, particularly among the less abundant species of fish.

Floodplain --

A floodplain located in the upper estuary zone near Bai Tenda, The Gambia, was sampled on 12-13 October 1983 during the peak flood stage, and again on 6-7 December 1983 during the declining water stage. The channel through which the water entered the floodplain was closed off with a 0.63-cm

(0.25-in) bar mesh net at high tide when the depth and extent of water on the floodplain was greatest. Rotenone was applied to the floodplain and, when the area had drained completely, the poisoned fish were collected by hand. This process was repeated for day and night flood tides, during the periods of peak flood and declining water. The area of the floodplain was 2,646 m^2 (26.5 hm^2), 75% of which was mud while the remainder was covered by mangroves or grasses.

All catches were small and ranged from 0.049 to 2.517 kg or 0.002-0.1 kg/hm^2 (Table 32). Standing stocks of fish were slightly higher during the period of peak flood than during the declining water stage. These biomasses are extremely low and show a near absence of fish in an area (floodplain habitat) that in other river systems is very productive and supports biomasses many times larger than those measured for the Gambia River.

In the Senegal River, Riezer (1974) measured standing fish stock in long narrow pools formed from isolated drainage channels at 205 $\pm$ 155 kg/hm^2 and 13 $\pm$ 6 kg/hm^2 for round depression pools. However, this study was conducted before the recent drought that has occurred over the past 10-15 years. More recent studies of the Senegal River indicate that the biological productivity of the river is low and that standing crops of fish are greatly reduced from those measured by Riezer. Welcomme (1979) summarized measurements of dry-season ichthyomass in pools and lagoons of 13 tropical floodplain rivers. Estimated ichthyomass ranged from 63 to 1,835 kg/hm^2. These measurements were made during the dry season when fish are crowded into reduced water volumes and densities are higher than during the wet season when the rivers are at peak flood and volume. Nonetheless, these data indicate the extremely low

TABLE 32. Standing stock of fish sampled on a 2,646 m^2 floodplain of the Gambia River, West Africa, 1983.

Date	Time	Taxon	Number of fish	Weight (kg)
12 Oct	0900	*Tilapia occidentalis*	53	1.929
		Periophthalmus papilio	37	0.215
		Hemichromis bimaculatus	4	0.124
		Porogobius schlegeli	109	0.083
		Liza falcipinnis	19	0.046
		Pellonula vorax	165	0.046
		Chrysichthys nigrodigitatus	1	0.036
		Aplocheilichthys normani	67	0.020
		Bostrychus africanus	4	0.010
		Hemichromis fasciatus	1	0.008
		Total	460	2.517
		Ichthyomass (kg/hm^2)		0.095
13 Oct	2030	*Periophthalmus papilio*	9	0.073
		Bostrychus africanus	3	0.063
		Chrysichthys nigrodigitatus	4	0.062
		Pellonula vorax	21	0.008
		Porogobius schlegeli	8	0.008
		Tilapia occidentalis	1	0.003
		Aplocheilichthys normani	3	0.001
		Liza falcipinnis	1	0.001
		Total	50	0.197
		Ichthyomass (kg/hm^2)		0.007
6 Dec	0650	*Bostrychus africanus*	4	0.031
		Liza falcipinnis	1	0.008
		Porogobius schlegeli	3	0.005
		Pellonula vorax	3	0.002
		Aplocheilichthys normani	3	0.003
		Total	14	0.049
		Ichthyomass (kg/hm^2)		0.002
7 Dec	1800	*Liza falcipinnis*	1	0.026
		Porogobius schlegeli	9	0.015
		Periophthalmus papilio	2	0.007
		Polydactylus quadrifilis	1	0.003
		Pellonula vorax	3	0.002
		Total	16	0.053
		Ichthyomass (kg/hm^2)		0.002

productivity of the Gambia River floodplains relative to other tropical river floodplains.

The reduced standing stock of fish on the Gambia River floodplain was probably the result of two conditions. First, the continuing drought and reduced flow of water and nutrients into the river has reduced all components of river productivity, including that of fish stocks. There are simply far fewer fish present in the river to migrate onto the floodplains. Second, most floodplains that we observed were almost entirely drained during low tide, even during the peak flood stage. This required most fish to migrate on and off the floodplains twice daily, and undoubtedly greatly curtailed spawning, because the spawning substrate and any deposited eggs were exposed twice daily to air, and once daily to intense heating by sunlight. The result of these conditions was the extremely low standing stock of fish on the floodplain. Conversations with local artisanal fishermen confirmed the trend toward reduction of fish stocks on the floodplains. Artisanal fishing in the floodplain reaches of the river was limited almost exclusively to the mouths of the bolons and within a few meters of the banks of the main river channel. The exceptions to this were the stake nets set for shrimp and the surround nets which were deployed in the offshore zone of the main river channel to trap *Ethmalosa fimbriata*.

Annual Yield

Annual yield was computed for portions of the existing river system based upon fishery catch statistics. But yield could only be predicted for the reservoirs. Therefore, analysis and discussion of annual yield has been separated into that for the existing river and for the proposed reservoirs.

Existing System --

The only direct measurement of annual yield for the Gambia River comes from catch surveys conducted by the Fisheries Department of The Gambia in Gambian waters of the river. The Service d'Eaux et Forets of Senegal began market catch surveys of river catch in eastern Senegal but preliminary results were not available in 1984.

A summary of catch statistics (Table 33) in Gambian waters of the Atlantic ocean and the Gambia River from 1978-1983 reveals a decline in catch from 32,085 metric tons in 1978 to 13,002 metric tons in 1983. The bulk of this decline occurred in the marine industrial fishing sector and the marine coastal sector of the artisanal fishery. Industrial fishing is limited to oceanic waters and very little effort is expended in the river itself, even near the coast (Dorr et al. 1983; Josserand 1984). Considerable yearly variation in catch by species occurred during 1979, 1981, and 1982 in the marine coastal artisanal fishery (Table 34).

TABLE 33. Artisanal and industrial fish catch (metric tons) recorded for The Gambia, West Africa, 1978-1983 (data from Fisheries Department, Ministry of Water Resources and Environment, The Gambia, as summarized in Josserand 1984).

Fishing sector	Year					
	1978	1979	1980	1981	1982	1983*
Artisanal						
Marine	11,199	8,284	10,255	11,055	6,196	2,381
Inland	N/D	2,795	3,489	1,423	3,508	386
Industrial[2]	20,086	10,295	10,752	9,624	7,377	3,734
Total	32,085	21,374	24,496	22,102	17,081	6,501

[1] (*). For January-June 1983 only.
[2] Industrial fishing catch records are incomplete for 1980, 1981, and 1983; therefore, annual catch is underestimated relative to other years.

TABLE 34. Marine coastal landings (metric tons) of finfish taken by the Gambian artisanal fishery during 1979, 1981, and 1982.

Taxon	1979[1]	1981[2]	1982[3]
ARIIDAE[4]			
Catfish	1,111.7	1,704.4	717.8
CARANGIDAE			
Carangidae		95.7	46.7
Trachurus trecae	50.8	49.6	49.6
CICHLIDAE			
Tilapia spp.		63.3	19.5
CLUPEIDAE			
Ethmalosa fimbriata	1,145.5	3,919.8	5,270.5
Sardinella spp.	14.0	21.8	38.5
CYNOGLOSSIDAE			
Cynoglossus senegalensis	117.2	158.1	65.3
EPHIPPIDAE			
Drepane africana	77.1	80.6	39.4
MUGILIDAE			
Liza falcipinnis		190.3	109.8
Mugil spp.	377.7		
POLYNEMIDAE			
Galeoides decadactylus	11.8	126.1	31.7
Polydactylus quadrifilis	472.6	344.2	112.6
POMADASYIDAE			
Pomadasys spp.		244.4	153.7
SCIAENIDAE			
Fonticulus elongatus	141.9	278.2	116.6
Pseudotolithus brachygnathus	547.4	927.7	317.7
Pseudotolithus macrognathus	60.4	103.0	16.8
Pseudotolithus senegalensis	614.9		338.5
Sciaenidae	161.0		
SERRANIDAE			
Epinephelus spp.	178.9	104.1	23.7
SPARIDAE			
Dentex spp.	98.9		5.3
SPHYRAENIDAE			
Sphyraena sphyraena	311.3	622.6	147.0

(continued)

TABLE 34. (continued).

Taxon	1979[1]	1981[2]	1982[3]
SQUALIFORMES, LAMINIFORMES, RAJIFORMES[5]			
Sharks, skates, rays	628.1	832.3	390.0
Unidentified	326.6	188.7	74.7
Total	6,448.6	10,054.9	8,080.4

1 Data summarized from: Drammeth, H.O. Various aspects of the domestic marketing of fish up-country. Fish Dept., Min. Water Res. Environ., Banjul. 34 pp. Unpublished manuscript.
2 Data summarized from Drammeh (1982).
3 Data summarized from Josserand (1984). Period of record covered July 1982-June 1983.
4 Probably _Arius_ spp. or _Galeichthys_ spp.
5 Species not designated but likely included members of the orders Lamniformes and Rajiformes listed in Table 3.

For the inland artisanal fishery, catch remained relatively stable between 1979-1982. But extrapolation of the 1983 catch based upon the first six-month statistics suggests a dramatic decline in annual catch from a 4-yr mean during 1979-1982 of 2,804 metric tons to 772 metric tons in 1983. Summary of the inland river catch during Jan-Dec 1980 and Jul 1982-Jun 1983 (Table 35) reflects a similar decline from 3,037 metric tons to 1,242 metric tons. Significantly, the decline occurred in the Lower River Division of The Gambia, which encompassed the portion of the river from Kaur downstream to Banjul. This portion includes all of the lower estuary and most of the upper estuary. Catch in the Upper River Division, the freshwater portions of the lower river from Kaur upstream to The Gambia/Senegal border, remained nearly identical for both periods. However, considerable variation in the annual catch by species occurred during 1977, 1979, and 1981-1982 (Table 36).

TABLE 35. Estimates of annual inland artisanal fishery catch (metric tons) and yield (kg/ha/yr)[1] for the Lower (Banjul to Kaur) and Upper (Kaur to Koina) River Divisions of The Gambia, West Africa, during 1980 and 1982-1983.

Division	Jan-Dec 1980[2]		Jul 1982-Jun 1983[3]	
	Catch	Yield	Catch	Yield
Lower river	2,406	37.59	605	9.45
Upper river	631	126.20	637	127.40
Total	3,037	42.77	1,242	17.49

1 Areas estimated as: Banjul to Deer Islands = 64,000 ha; Deer Islands to Gouloumbou, Senegal = 5,000 ha; total area of river in The Gambia = 71,000 ha.
2 Estimates of catch from Lesack 1986.
3 Estimates of catch from Josserand 1984.

These data (Tables 33-36) indicate three general trends in annual catch from 1978-1983: the industrial marine catch has declined, the artisanal fishery catch has declined in the estuarine portions of the river, and catch in the freshwater portion of the river contained in The Gambia has remained relatively stable in comparison with the other two fishing sectors.

No evidence for diminished standing crops of marine fish targeted by the industrial fishing sector (primarily sardines, solefish, and a few other high-value species) was compiled. But considerable variation has occurred in fish effort during this period, especially among foreign-owned vessels (Josserand 1984). It is likely that the apparent decline in the industrial fishery is more a function of variable levels of effort combined with incomplete catch records, rather than a reflection of declining standing crops or annual production. The same may not be true for the marine and estuarine portions of the river located between Kaur and Banjul.

Unfortunately, although records of artisanal catch in Gambian waters of the river have been compiled in varying detail since 1978, concurrent records

TABLE 36. Riverine landings (metric tons) of finfish taken by the artisanal fishery on the Gambia River during 1977, 1979, 1981, and 1982.

Taxon	1977[1]	1979[1]	1981[2]	1982[3]
ARIIDAE[4]				
Catfish			278.5	118.1
ALESTIDAE				
Alesle spp.			1.1	6.3
Hydrocynus spp.	10.0	9.2	3.1	2.8
BAGRIDAE				
Auchenoglanis occidentalis	43.5	43.6		
Chrysichthys spp.	102.3	5.1	85.5	85.5
CARANGIDAE				
Carangidae			23.4	
CICHLIDAE				
Tilapia spp.	122.1	1,203.0	73.3	0.8
CITHARINIDAE				
Citharinus citharus			18.8	16.7
CLARIDAE				
Clarias spp.	143.1	29.3	5.1	30.5
CLUPEIDAE				
Ethmalosa fimbriata			256.1	161.5
CYNOGLOSSIDAE				
Cynoglossus senegalensis			10.1	1.0
CYPRINIDAE				
Labeo spp.	18.3	13.1		
ELOPIDAE				
Elops spp.			1.4	10.9
EPHIPPIDAE				
Drepane africana			5.7	
MOCHOEIDAE				
Synodontis spp.			12.9	0.8
MUGILIDAE				
Liza falcipinnis			2.6	44.7
OSTEOGLOSSIDAE				
Heterotis niloticus	11.2	9.5	5.2	27.3

(continued)

TABLE 36. (continued).

Taxon	1977[1]	1979[1]	1981[2]	1982[3]
POLYNEMIDAE				
Polydactylus quadrifilis		92.1	358.2	146.2
POMADASYIDAE				
Pomadasys spp.			0.1	0.2
SCIAENIDAE				
Fonticulus elongatus			130.1	46.0
Pseudotolithus brachygnathus			28.9	17.3
Pseudotolithus macrognathus			8.9	211.6
Pseudotolithus senegalensis			19.3	37.7
SQUALIFORMES, LAMINIFORMES, RAJIFORMES[5]				
Sharks, skates, rays			25.8	21.5
SPHYRAENIDAE				
Sphyraena sphyraena			94.8	
Other	419.4	45.5	51.2	211.6
Total	869.9	1,650.4	1,508.7	1,390.3

1 Data summarized from: Drammeth, H.O. Various aspects of the domestic marketing of fish up-country. Fish Dept., Min. Water Res. Environ., Banjul. 34 pp. Unpublished manuscript.
2 Data summarized from Drammeh (1982).
3 Data summarized from Josserand (1984). Period of record covered July 1982-June 1983.
4 Probably *Arius* spp. or *Galeichthys* spp.
5 Species not designated but likely includes members of the orders Lamniformes and Rajiformes listed in Table 3.

of fishing effort are not available for this period. Therefore, it is not possible to state conclusively that standing crops or annual production have declined during this period. However, two sources of evidence support this conclusion.

Through direct conversations with members of our team or other investigators that we interviewed, fishermen on the river overwhelmingly stated that catches have declined over the past 10 years, and particularly during the last 5 years. According to these fishermen, this decline occurred despite continued levels of fishing effort. Although total effort may now be reduced relative to previous levels, this reduction occurred in response to declining catch and movement to other occupations and was not the causative factor of the decline.

The second source of evidence comes from the numbers of active fishermàn and their inventory of vessels, gear, and other fishing equipment recorded during the annual frame surveys conducted by the Fisheries Department of The Gambia. These records show that the decline in riverine catch is not paralleled by an equivalent reduction in numbers of master fishermen or in their inventory of gear. Again, this suggests that if standing crop, annual production, and yield have diminished over the past several years, it is not primarily a function of reduced fishing effort. For reasons to be discussed later, it is also not a function of overfishing.

Our conclusion is that annual production in the marine and estuarine portions of the river has declined considerably over the past 10 years. Based upon our studies and catch data from 1983 as well as reports on catches and environmental conditions during 1984, a continuation of this decline in annual production is anticipated, perhaps with increasing severity if the

drought and reduction in annual influx of fresh water to the river system continue. The problem appears to be most severe in the estuarine and marine portions of the river. However, if sufficient catch and effort data were available, the portions of the river suffering the most severe decline in annual production would undoubtedly be shown to be the floodplain and estuarine areas. Upstream of these areas, the river is generally confined within a main channel even during the flood period and acts as a sluice for water, nutrients, and detritus moving downstream to the estuary and floodplains. Below these areas, the river is dominated by tidal effects and near marine conditions which buffer the seasonal fluctuations and inputs of the river from upstream.

Welcomme (1979) summarized estimates of ichthyomass in floodplain pools and lagoons made during the dry season in 14 different tropical river systems. Values ranged from 6,300 to 183,500 kg/ha; all greatly exceed the 126 kg/ha predicted for the Gambia River. A University of Michigan (Lagler et al. 1971) study of the Kafue River and floodplain in Zambia estimated high water ichthyomasses for open-water lagoon, vegetated lagoon, grass marsh, and river channel habitat as 33,700, 26,820, 6,400, and 33,700 kg/ha, respectively. Low water ichthyomass for river channel, open-water lagoon, and vegetated lagoon were estimated as 20,400, 42,600, and 59,200 kg/ha, respectively. Welcomme (1979) stated that although it is difficult to establish reliable levels of maximum sustained yield (MSY) for tropical floodplain rivers, 4,000-6,000 kg/ha is a reasonable estimate for the flood season.

All of these estimates greatly exceed the 1980 and 1982-1983 annual yields of 38 and 10 kg/ha calculated for the marine and estuarine portion of the Gambia River, and 126 kg/ha estimated for the freshwater reaches of the

river in The Gambia which include the floodplains. At least two possible explanations exist for the low yield from the existing fisheries in The Gambia. It is quite likely that these fisheries are underexploited and could sustain a doubling in fishing effort and annual harvest. This assumes that the current fishery operate at 50% of MSY; in fact, it may be operating at levels considerably below this. The other consideration is that the floodplains, swamps, lagoons, and bolons of tropical floodplain rivers constitute the bulk of total system production. The recent drought and consequent reduction in production from these habitats has greatly reduced total system yield in The Gambia. Finally, there are no catch survey data available on historical yields of the Gambia River system prior to the drought. It may be that 10-15 years ago total yield more closely approached that cited above for other floodplain rivers.

Based upon our study and available catch statistics, it is unlikely that total inland artisanal fishery catch in Gambian waters of the river will exceed 2,000 metric tons per annum, assuming that the current (although unidentified) level of effort does not increase. It is possible that total annual catch will be considerably less than this amount. This decline will continue most extensively in the estuarine and floodplain regions and fisheries, but will be felt in other portions of the river.

It is more difficult to predict what will occur in the upstream freshwater reaches of the river in Senegal and Guinea. The limited evidence that we have indicates that annual production in the Senegalese portion of the river has decreased (fishermen reported declines in annual catch corresponding with the drought) and will continue if the drought continues. But much of the Senegalese portion of the river lies within the the National Park (Niokolo

Koba) where fishing is presumably already limited and catch records are not maintained. Therefore, continued reduction in annual production would have less effect on fishermen and the human population in this region of the river, because current levels of exploitation and dependency are low relative to areas outside of the park.

Little is known regarding current annual production in Guinean waters of the river, or levels of exploitation and human dependency on the fishery. Our studies have amassed baseline information on species distribution and relative abundance, as well as providing preliminary understanding of the ecology of fish in this portion of the river. Direct measurement of current annual production in this portion of the river was not within the scope of work for this project. However, based upon observations and samples taken during the February 1983 reconnaissance of the drainage system in Guinea, and the three major samplings conducted during November 1983, February 1984, and June 1984, combined with extensive discussions with staff of other teams on the project, we concluded that annual production per unit area (kg/ha) is considerably less in the upper reaches of the river in Guinea than in its lower reaches in The Gambia.

Primary productivity was not measured at the Guinea sampling site, but values for water chemistry parameters (conductivity, alkalinity, pH) and nutrient levels (nitrogen, phosphorus, silica) suggest that the water is relatively soft and unproductive in comparison with the lower reaches of the river.

Species diversity of macrobenthos was found to be high in the headwaters zone in accordance with the wide spectrum of ecological niches available in

this region. But total numbers (and most likely production, too) were low relative to the other river zones.

Therefore, the component of fish production that is dependent upon nutrient input, primary productivity, and production of benthic invertebrates is undoubtedly limited by the relatively low levels of these factors.

Proposed Reservoirs --

An attempt was made to predict annual yield for the five reservoirs proposed for the Gambia River. Four general models were used: morphoedaphic index (conductivity), total phosphorus, primary productivity, and catch survey data. Methods for calculation are detailed in Appendix 4 and parameters used in the models are summarized in Appendix 5. Values for these parameters were developed using our field measurements or best estimates. It is quite possible that more accurate or representative values for these parameters may be developed in the future. The present estimates represent the best that can be done with the existing database and establish a methodology that can be duplicated and refined during future analyses using additional information.

Estimates of annual yield using morphoedaphic index (Table 37), total phosphorus (Table 38), and primary productivity (Table 39) used both measured and estimated parameter values. Unadjusted yield was predicted for each hydrological stage and then adjusted to seasonal yield according to the duration of that stage. From this, total annual adjusted yield per hectare was calculated, and finally annual yield in metric tons was predicted.

Estimates of annual yield based on existing fishery catch statistics (Table 40) assumed that yield per hectare for the reservoirs would at least equal that of the existing riverine fishery.

TABLE 37. Annual yield and economic value of fish from reservoirs proposed for the Gambia and tributary rivers, West Africa, predicted from morphoedaphic data (see Appendices 4 and 6).

Reservoir	Hydrological stage of river: Rising water	Peak flood[1]	Declining water	Low water
	Unadjusted annual yield (kg/ha/yr)			
Balingho	133.15	97.57	109.87	132.40
Kekreti	93.15	64.64	76.34	102.79
Kouga-Foulbe	91.54	67.14	69.31	107.94
Kankakoura	80.49	59.04	60.95	94.92
Kouya	52.28	38.38	39.59	61.67
	Seasonal yield (kg/ha/yr)[2]			
Balingho	22.19	24.39	27.47	44.13
Kekreti	15.53	16.16	19.09	34.26
Kouga-Foulbe	15.26	16.79	17.33	35.93
Kankakoura	13.42	14.76	15.24	31.64
Kouya	8.71	9.60	9.90	20.56

	Seasonally-adjusted annual yield (kg/ha/yr)[3]	Total annual yield (metric tons)	Economic value (millions)[4]
Balingho	118.18	5,681	8.5
Kekreti	85.04	1,488	446.1-595.2
Kouga-Foulbe	85.31	177	53.1-70.8
Kankakoura	75.06	34	10.2-13.6
Kouya	48.77	265	79.5-106.0

1 Rising water conductivity was substituted for missing values during peak flood for Guinean reservoirs.

2 Duration of hydrological stage was estimated as: rising water = 2 mo, peak flood = 3 mo, declining water = 3 mo, low water = 4 mo.

3 Seasonal adjustment = duration of stage x reservoir area at stage (see Appendix 6 for areas).

4 Estimate for Balingho Reservoir based upon March 1984 average (combined species) market price in Farafenni, The Gambia, of 1.5 dalasis/kg for fresh fish. Estimates for other reservoirs based upon March 1984 market price in Kedougou, Senegal, of 300-400 CFA/kg for fresh fish (Josserand 1984).

TABLE 38. Annual yield and economic value of fish from reservoirs proposed for the Gambia and tributary rivers, West Africa, predicted from total phosphorus data (see Appendices 4 and 6). Data and estimates were not available for the Guinean reservoirs.

Reservoir	Hydrological stage of river: Rising water	Peak flood[1]	Declining water	Low water
	Unadjusted annual yield (kg/ha/yr)			
Balingho	1.67	1.34	1.42	1.29
Kekreti	1.99	1.99	1.16	1.41
Kouga-Foulbe				
Kankakoura				
Kouya				
	Seasonal yield (kg/ha/yr)[1]			
Balingho	0.28	0.34	0.36	0.43
Kekreti	0.33	0.50	0.29	0.47
Kouga-Foulbe				
Kankakoura				
Kouya				

	Seasonally-adjusted annual yield (kg/ha/yr)[2]	Total annual yield (metric tons)	Economic value (millions)[3]
Balingho	1.41	68	0.1
Kekreti	1.59	28	8.4-11.2
Kouga-Foulbe			
Kankakoura			
Kouya			

[1] Duration of hydrological stage was estimated as: rising water = 2 mo, peak flood = 3 mo, declining water = 3 mo, low water = 4 mo.

[2] Seasonal adjustment = duration of stage x reservoir area at stage (see Appendix 6 for areas).

[3] Estimate for Balingho Reservoir based upon March 1984 average (combined species) market price in Farafenni, The Gambia, of 1.5 dalasis/kg for fresh fish. Estimates for other reservoirs based upon March 1984 market price in Kedougou, Senegal, of 300-400 CFA/kg for fresh fish (Josserand 1984).

TABLE 39. Annual yield and economic value of fish from reservoirs proposed for the Gambia and tributary rivers, West Africa, predicted from primary productivity data (see Appendices 4 and 6).

Reservoir	Hydrological stage of river: Rising water	Peak flood	Declining water	Low water
	Unadjusted annual yield (kg/ha/yr)[1]			
Balingho	77.33	10.37	10.52	13.46
Kekreti	8.55	8.55	21.39	24.83
Kouga-Foulbe	14.18	14.18	9.68	13.69
Kankakoura	14.18	14.18	9.68	13.69
Kouya	14.18	14.18	9.68	13.69
	Seasonal yield (kg/ha/yr)[2]			
Balingho	12.89	2.59	2.63	4.49
Kekreti	2.14	2.14	5.35	8.28
Kouga-Foulbe	2.36	2.36	2.42	4.56
Kankakoura	2.36	2.36	2.42	4.56
Kouya	2.36	2.36	2.42	4.56

	Seasonally-adjusted annual yield (kg/ha/yr)[3]	Total annual yield (metric tons)	Economic value (millions)[4]
Balingho	22.60	809	1.2
Kekreti	17.91	313	93.9-125.2
Kouga-Foulbe	11.70	24	7.2-9.6
Kankakoura	11.70	5	1.5-2.0
Kouya	11.70	64	19.2-25.6

1 Estimates for rising water and peak flood were substituted interchangeably when lack of primary productivity data (Appendix 6) prohibited direct calculation of yield for either hydrological stage.

2 Duration of hydrological stage was estimated as: rising water = 2 mo, peak flood = 3 mo, declining water = 3 mo, low water = 4 mo.

3 Seasonal adjustment = duration of stage x reservoir area at stage (see Appendix 6 for areas).

4 Estimate for Balingho Reservoir based upon March 1984 average (combined species) market price in Farafenni, The Gambia, of 1.5 dalasis/kg for fresh fish. Estimates for other reservoirs based upon March 1984 market price in Kedougou, Senegal, of 300-400 CFA/kg for fresh fish (Josserand 1984).

TABLE 40. Annual yield and economic value of fish from reservoirs proposed for the Gambia River in The Gambia and Senegal, West Africa, predicted from existing artisanal fishery catch data (Table 35). Predictions assumed that yield per hectare for the reservoirs would be equal to that of the existing riverine fishery.

Reservoir[1]	Seasonally-adjusted annual yield (kg/ha/yr)	Total annual yield (metric tons)	Economic value (millions)[2]
Balingho	126	6,325	9.5
Kekreti	95	2,176	652-870

1 Catch data were unavailable for the portion of the river in Senegal. But seasonally-adjusted annual yield predicted from morphoedaphic (Table 4), total phosphorus (Table 5), and primary productivity (Table 8) data suggest that annual yield of the Kekreti Reservoir should be at least 75% that of the Balingho Reservoir.

2 Estimate for Balingho Reservoir based upon March 1984 average (combined species) market price in Farafenni, The Gambia, of 1.5 dalasis/kg for fresh fish. Estimates for other reservoirs based upon March 1984 market price in Kedougou, Senegal, of 300-400 CFA/kg for fresh fish (Josserand 1984).

The catch assessment model predicted highest annual yield, followed closely by morphoedaphic index. Estimates based upon primary productivity and total phosphorus were 10- and 100-fold less, respectively, than yields predicted by the first two models. This range in values was not unexpected. In the floodplain and estuarine reaches of the river, system production is heavily dependent upon the input of detritus from the swamps, terrestrial vegetation, and mangroves as discussed earlier. Levels of total phosphorus are low, in part, because there is little anthropogenic input relative to other rivers in more populated parts of the world. Large amounts of suspended sediment occur in the river, which reduces water transparency and penetration of light, resulting in the limitation of primary productivity to the upper few meters of the water column. Most likely, estimates of annual production and

yield based on primary productivity and total phosphorus would greatly underestimate the capacity of the system. However, they do place lower limits on expected range of values. Annual yield predicted by the catch assessment and morphoedaphic models were within the same range of magnitude. This is not surprising since the morphoedaphic model was developed empirically from data on conductivity and fish yield from several African reservoirs (Marshall 1983). A critical and quite possibly inaccurate assumption of the catch assessment model was that yield per hectare would be the same for the reservoirs as it was for the existing riverine fishery despite the major alterations in the environment, ecology, and population structure of fish stocks. However, we had no other data or insight to justify increasing or decreasing the estimate of reservoir yield in relation to riverine yield. Further discussion of possible deviations from this assumption are presented below.

Comparisons of annual yield predicted by the four models show a wide range in values (Table 41). For Balingho, estimates ranged from 68 to 6,325 metric tons annually, a 100-fold range in yield. Certainly, the first value represents the low end of expected yield, once fish stocks recover and stabilize following the alterations in river system. It is quite possible that annual yield could exceed 6,000 metric tons. This estimate was based upon the assumption of an average yield of 126 kg/ha which was equivalent to that realized by the existing fishery in the freshwater portion of the river in The Gambia during 1980 and 1982-1983 (Table 35).

Estimates of total annual yield predicted for the Kekreti Reservoir followed the same general pattern as discussed for Balingho. Predicted yield ranged from 28 to 2,176 metric tons annually (Table 41). Again, the total

TABLE 41. Summary of estimates of annual yield and economic value of fish from proposed reservoirs on the Gambia and tributary rivers, West Africa. N/A = not available.

Method of estimate[1]	Reservoir				
	Balingho	Kekreti	Foulbe	Kogou-Kankakoure	Kouya
	Total annual yield (metric tons)				
Catch	6,325	2,176	N/A	N/A	N/A
MEI	5,681	1,488	177	34	265
PP	809	313	24	5	64
TP	68	28	N/A	N/A	N/A
	Economic value (millions)[2]				
Catch	9.5	652-870	N/A	N/A	N/A
MEI	8.5	446.1-595.2	53.1-70.8	10.2-13.6	79.5-106.0
PP	1.2	93.9-125.2	7.2-9.6	1.5-2.0	19.2-25.6
TP	0.1	8.4-11.2	N/A	N/A	N/A

1 Location of data: catch assessment estimates (Catch) = Table 40, morphoedaphic index estimates (MEI) = Table 37, primary productivity estimates (PP) = Table 39, total phosphorus estimates = Table 38.

2 Estimate (dalasis) for Balingho Reservoir based upon March 1984 average (combined species) market price in Farafenni, The Gambia, of 1.5 dalasis/kg for fresh fish. Estimates (CFA) for other reservoirs based upon March 1984 market price in Kedougou, Senegal, of 300-400 CFA/kg for fresh fish (as cited in Josserand 1984).

phosphorus and primary productivity models likely underestimated yield for reasons discussed earlier. Since catch assessment data were unavailable for the existing fishery in this reach of the river, annual yield was assumed to be 75% (or 95 kg/ha) of that realized in the lower reaches where catch assessment data were available. This assumption was supported by comparison of yields per hectare predicted by the other three models using values for model parameters measured in the field at both locations (i.e., in the vicinity of the Balingho and Kekreti sites). Again, for reasons presented in the discussion of predicted yield from the Balingho Reservoir, an annual yield of 2,176 metric tons for the Kekreti Reservoir may be a rather conservative estimate. It is possible that annual yields of 4,000-5,000 metric tons might be realized depending on the composition, exploitation, and management of fish stocks that may inhabit the Kekreti Reservoir as it stabilizes and matures.

For the Guinean reservoirs, data were available only for the morphoedaphic and primary productivity models, which predicted annual yields ranging from 5 to 265 metric tons annually. But if catch assessment data were available and predictions paralleled those for the Balingho and Kekreti Reservoirs, annual yields of several hundred to 1,000 metric tons might be realized for the Guinean reservoirs.

A summary of annual yield from nine African lakes (Melack 1976) showed that annual yield ranged from 14 to 152 kg/ha. These values may reflect better estimates of annual yield that may be realized from the proposed reservoirs on the Gambia River, than those cited earlier for floodplain rivers.

These estimates of annual yield for the five reservoirs are admittedly wide-ranging both in their assumptions and predictions. However, they do

establish general upper and lower limits to the annual yield that may be expected from these reservoirs based upon analysis and predictions from available data. In time, as additional data, observations, and comparisons are accrued, these estimates may be refined and projected with greater confidence. As they are, they form a basis to begin system analyses and predictions related to environmental and economic considerations.

FUTURE MONITORING, ASSESSMENT, AND MANAGEMENT

A major part of the success of the development programs of the Gambia River Basin will require recognition of potential fishery resources followed by effective exploitation and management of these resources. Three general steps are required to accomplish the above tasks: (1) fish stock evaluation and biological monitoring, (2) implementation of adequate catch-assessment surveys, and (3) development of a resource policy and management program.

The GRBS has completed many of the steps needed to make preliminary evaluations of fish and shellfish stocks existing in the river. In particular, estimates of both existing and predicted post-development stocks have been made. But additional studies that were beyond the scope of this project are needed to evaluate and project changes in specific target stocks after a specific development scenario has been implemented. Without adequate and ongoing information on population parameters of specific species, these stocks cannot be fished and managed using modern techniques.

An aquatic monitoring program will be required to provide information regarding the physical, chemical, and biological conditions in the river and reservoirs. This program will compile critical information that can describe current environmental conditions as well as the response of the river eco-

systems to changes, particularly those associated with development activities. In turn, the information from the monitoring program is required to place fishery stock assessment data into perspective with respect to the environmental factors which dictate the growth and survival of animal populations. Suggestions regarding both stock assessment and monitoring programs are contained in this and other GRBS reports.

Ongoing monthly and annual fisheries catch-assessment surveys have been in existence in The Gambia since 1980. These surveys, while deficient in some critical areas such as compilation of data on overall fishing effort or effort-by-gear, provide an excellent basis for the implementation of an expanded catch-assessment program. Much of the groundwork and effort required to organize and implement such a program has already been expended with considerable success. At this point, the existing catch-assessment survey program in The Gambia has reached a critical stage. Additional assistance and guidance are needed in the areas of fiscal support and development of data assessment objectives, to ensure the compilation of information according to identified analytical needs. These needs must be established according to the goals set for river basin development and overall production.

Catch-assessment survey programs have not yet been established in Senegal or Guinea; these programs will fill future needs if the proposed reservoir development occurs in the upper river basin. Not only must these survey programs be conceived and implemented, but their coordination with the survey in the Gambian reaches of the river is critical if a coordinated program of basin development is desired.

Finally, there is a requirement to identify short- and long-term analytical objectives based upon the need to evaluate, develop, and manage the fish-

ery resources in the basin and adjoining coastal waters. The river system should be considered an integrated unit in need of a masterplan regarding the exploitation and management of fisheries, if maximum benefits are to be realized from these resources.

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APPENDIX 1. Gear used in the collection of Gambia River fish, 1983-1984. Mesh sizes are bar measure.

Gear	Abbreviation	Specifications
		Passive gear
Gill net	SG or BG	1.8 m x 36.6 m composed of twelve 3.0 m panels of netting of the following mesh sizes: 1.3 cm, 1.9 cm, 2.5 cm, 3.2 cm, 3.8 cm, 4.4 cm, 5.1 cm, 5.7 cm, 6.4 cm, 7.0 cm, 7.6 cm, and 10.2 cm.
Trap net	TN	"Indiana" style (Sterling Net and Twine Co., Bangor, Maine). Single 0.9 m x 15.2 m lead; double 0.9 m x 6.1-m wing; 0.9 m x 1.8-m rectangular mouth, 1.0-m deep with front and rear internal steel rod supporting frame; 2.3 m x 0.8-m diameter box with four internal steel rod supporting hoops and four adjustable throats. All netting 0.6-cm mesh.
Blocking net	BL	Composed of four 1.8 m x 30.5-m panels of 0.6-cm mesh.
Long line	LL	45.7-m main line; twenty-five 0.3-m staging lines with 3/0 "Limerick" style hook (Nylon Net Co., Memphis, Tennessee).
		Active gear
Seine	SS	1.8 m x 3.7 m with 0.2-cm mesh.
Seine	BS	1.8 m x 15.2 m with 1.8 m x 1.8 m x 1.8-m bag; entire seine of 0.6-cm mesh.
Cast net	CN	1.8-m radius; 0.6-cm mesh.
Trawl	BT or PT	Semi-balloon type having a 4.9-m headrope and 5.8-m footrope; body and cod end composed of 1.9-cm mesh; cod end interliner composed of 0.6-cm mesh.
Trawl	ST	Semi-balloon type, shrimp try net design having a 3.0-m headrope and 3.6-m footrope; body and cod end composed of 1.9-cm mesh; cod end interliner composed of 0.6-cm mesh.
Plankton net	none	Bridleless, no. 2 (363 micron) mesh, 0.5-m diameter equipped with a center-mounted General Oceanics Model 2030 flowmeter which was used to convert numbers of fish larvae captured to no./1,000 m^3.

(continued)

APPENDIX 1. Continued.

Gear	Abbreviation	Specifications
		<u>Ancillary collecting gear</u>
Rotenone	none	Five percent rotenone, 10% other cube extracts, 85% inert emulsifiers.
Echolocator	none	Ross SL-100D Straight Line Recorder (Ross Laboratories, Seattle, Washington)
Electrofisher	none	Smith-Root, Inc. (Vancouver, Washington), Model 5.0 GPP. Conductivity range: 10-600 microsiemen/cm^3, output: AC - 120 pps, DC (adjustable) - 40-80 pps 400 watts peak power output.
Electrofisher	none	Smith-Root, Inc. (Vancouver, Washington), Model VIII. Conductivity range: 50-200 microsiemen/cm^3, output: DC - 40-50 pps, 400 watts peak power output.

APPENDIX 2. Distribution of adult and larval fish sampling effort during studies on the Gambia River, West Africa, 1983-1984. Gear are abbreviated as follows: BG = bottom gill net; BL = blocking net; BS = 15-m seine; BT = bottom trawl; CN = cast net; DF = drifting gill net; ES = electroshocker; LT = larvae tow; PT = pelagic trawl; RT = rotenone; SG = surface gill net; SS = 4-m seine; ST = shrimp try net; TN = trap net. Number of samples in parentheses.

Field Trip	Zone	Date	River Survey: Standard Series	River Survey: Supplemental	Special Studies: Bolon/Mangrove	Special Studies: Floodplain
1	Upper	25 Jun 83		LT(2) SS(9)		
	Freshwater	26 Jun 83		LT(3) SS(24)		
		27 Jun 83		SS(1)		
	Lower	22 Jul 83	BG(4) LT(4) SG(4)	ST(2)		
	Freshwater	23 Jul 83	BG(4) LT(4) SG(4)			
		24 Jul 83	BG(8) LT(8) SG(8)			
		25 Jul 83		BG(4)		
	Upper	26 Jul 83		BG(1) SG(1)		
	Estuary	28 Jul 83	BG(8) LT(8) SG(8)			
		29 Jul 83	BG(4) LT(4) SG(4)			
		30 Jul 83		BG(1) BT(3) DG(2)	BG(5) LT(4)	
	Lower	2 Aug 83	LT(4)	BG(2) BT(4) PT(4)		
	Estuary	3 Aug 83	LT(7)	BG(4) BT(6) PT(6)		
		4 Aug 83	LT(4)	BT(4) PT(4) SG(2)		
2	Upper	29 Sep 83	BG(8) LT(8)			
	Freshwater	30 Sep 83	BG(8) LT(8)	BG(4)		
	Lower	3 Oct 83	BG(8) LT(8) SG(8)			
	Freshwater	4 Oct 83	BG(4) LT(4) SG(4)			
		5 Oct 83	BG(4) LT(4) SG(4)			
	Upper	6 Oct 83		CN(1)		
	Estuary	7 Oct 83	BG(8) LT(8) SG(8)			
		8 Oct 83	BG(4) LT(4) SG(4)			
		9 Oct 83	BG(4) LT(4) SG(4)	BT(3) PT(3)	BG(1) ES(1)	
		11 Oct 83			LT(10)	LT(2)
		12 Oct 83			RT(1) SG(1)	BL(1)
		13 Oct 83			RT(1)	BL(1) RT(1)

(continued)

APPENDIX 2. Continued.

Field Trip	Zone	Date	River Survey: Standard Series	River Survey: Supplemental	Special Studies: Bolon/Mangrove	Special Studies: Floodplain
	Lower Estuary	28 Oct 83	BG(4) LT(8) SG(4)			
		29 Oct 83	BG(4) SG(4)	BS(2) ST(5)		
		30 Oct 83	BG(8) LT(8) SG(8)	BS(3)		
		31 Oct 83		SG(1)		
		8 Nov 83		BT(10)PT(6)		
3	Headwater	4 Dec 83	BG(1)	TN(1) SS(1)		
		5 Dec 83	BG(4)	TN(1)		
		6 Dec 83	BG(2) LT(4)	TN(1) SS(1)		
	Upper Freshwater	9 Dec 83	BG(4) LT(8)	BS(3)		
		10 Dec 83	BG(8) LT(4)			
		11 Dec 83	BG(2) LT(4) SG(2)			
	Mid-freshwater	13 Dec 83		BS(1) LT(4)		
	Lower Freshwater	1 Dec 83	BG(4) LT(4) SG(4)			
		2 Dec 83	BG(8) LT(8) SG(8)			
		3 Dec 83	BG(4) LT(4) SG(4)			
	Upper Estuary	6 Dec 83	BG(4) LT(4) SG(4)			SS(1)
		7 Dec 83	BG(8) LT(8) SG(8)	DG(1)		SS(1)
		8 Dec 83	BG(4) LT(4) SG(4)	BT(4) LT(2)		
	Lower Estuary	14 Dec 83	BG(4) LT(4) SG(4)	BT(4)		
		15 Dec 83	BG(8) LT(8) SG(8)	BT(5)		
		16 Dec 83	BG(4) LT(4) SG(4)			
4	Headwater	4 Mar 84	BG(5) LT(4)	SS(2)		
		5 Mar 84	BG(1)			
	Upper Freshwater	7 Mar 84	BG(2) LT(4)			
		8 Mar 84	BG(4) LT(4)	SS(4)		
		9 Mar 84	BG(2) LT(8)	SS(4)		

(continued)

APPENDIX 2. Continued.

Field Trip	Zone	Date	River Survey: Standard Series	River Survey: Supplemental	Special Studies: Bolon/Mangrove	Special Studies: Floodplain
	Lower Freshwater	9 Mar 84	BG(8) LT(8) SG(8)	BT(2) PT(2)		
		10 Mar 84	BG(8) LT(8) SG(8)	BT(2) PT(2)		
	Upper Estuary	1 Mar 84			BG(8) LT(4)	
		2 Mar 84			BG(4) ES(1)	
		3 Mar 84			BG(4)	
		5 Mar 84	BG(8) LT(12) SG(8)		RT(1)	
		6 Mar 84	BG(8) LT(4) SG(8)	BT(4) PT(4)		
	Lower Estuary	31 Jan 84		BT(8) PT(8)		
		20 Feb 84	BG(4) LT(4) SG(4)			
		21 Feb 84	BG(4) LT(4) SG(2)	BT(2) PT(2)		
		22 Feb 84	BG(4) LT(4) SG(6)	BT(2) PT(2)		
		23 Feb 84	BG(4) LT(4) SG(4)			
5	Headwater	4 Jun 84	BG(3)			
		5 Jun 84	BG(3) LT(2)	SS(4)		
		6 Jun 84	BG(2) LT(2)	RT(1)		

APPENDIX 3. Scientific, common, and local names of fish occurring in The Gambia's territorial waters.

Family and Scientific Name	Code	English	Mandinka	Wollof	Pulaar
ALESTIDAE					
Alestes barenose (Joannis)	AB		Koula auleo	Balanta	Debere/Andone
Alestes dentexi (Linnaeus)	AD		Balantang	Balanta	Debere
Brycinus longipinnis (Gunther)	BL				
Brycinus nurse (Rupell)	BN				
Hemigrammopetersius septentrionalis (Boulenger)	HS				
Hydrocynus brevis (Gunther)	HB	Tigerfish?			
ARIIDAE					
Arius heudeloti Valenciennes	AH	Catfish	Kunkelengo	Kong/Ngunja	
Arius latiscutatus Gunther	AL	Catfish	Kunkelengo	Kong/Ngunja	
Arius mercatoris Poll	AM	Catfish	Kunkelengo	Kong/Ngunja	
Arius parki Gunther	GF	Catfish			
Galeichthys feliceps Valenciennes					
BAGRIDAE					
Auchenoglanis occidentalis (Valenciennes)	AO	Catfish	Kosso wulengo		Ngukhlo/Ngurlo
Chrysichthys furcatus Gunther	CF	Catfish	Wallinyaba	Sesseh	Loumo
Chrysichthys nigrodigitatus (Lacepede)	CN	Catfish	Wallinyaba	Sesseh	Loumo
BATRACHOIDIDAE					
Halobatrachus didactylus (Schneider)	HA	Toadfish?	Babendango	Poursaguge	
BELONIDAE					
Strongylura senegalensis (Valenciennes)	SS	Half beak? Needle-nose fish?			
BOTHIDAE					
Citharichthys stampflii (Steindachner)	CS	Flatfish			

(continued)

APPENDIX 3. (Continued).

Family and Scientific Name	Code	English	Mandinka	Wollof	Pulaar
CARANGIDAE			Fetta	Sacca	
Caranx senegallus Cuvier	CX	Crank	Duduwo	Gonda	Enou
Chloroscombrus chrysurus (Linnaeus)	CC				
Hemicaranx bicolor (Gunther)	HE				
Trachinotus falcatus (Linnaeus)	TF				
CARCHARHINIDAE					
Carcharhinus limbatus (Valenciennes)	CL?	Shark			
CICHLIDAE					
Hemichromis bimaculatus Gill	HC	Hemichromis	Niakito/Kakolibo	Bosse/Kakolib	
Hemichromis fasciatus Peters	HF	Hemichromis	Niakito/Kakolibo	Bosse/Kakolib	
Tilapia brevimanus Boulenger	TB	Tilapia	Furro	Wass	
Tilapia galilaea (Artedi)	TG	Tilapia	Furro	Wass	
Tilapia heudeloti Dumeril	TH	Tilapia	Furro	Wass	
Tilapia occidentalis Daget	TO	Tilapia	Furro	Wass	
Tilapia rheophila Daget	TR	Tilapia	Furro	Wass	
Tilapia spp.	TX	Tilapia	Wakalo		Sidere
Tylochromis ujentinki (Steindachner)	TJ				
CLARIIDAE					
Clarias anguillaris linnaeus	CA	Walking catfish	Conocono	Yhass	Baleou
Clarias lazera Valenciennes	CZ	Walking catfish	Conocono	Conocono	Baleou
Clarias senegalensis Valenciennes	CY	Walking catfish	Conocono	Conocono	Baleou
Heterobranchus bidorsalis St. Hilaire	HT		Kandang/Pollio		Ndowa
Heterobranchus longifilis Valenciennes	HL		Kandang/Pollio	Ndowa	
CLUPEIDAE					
Ethmalosa fimbriata (Bowdich)	EF	Bonga	Chalo	Kobo	
Ilisha africana (Bloch)	IA	Shad	Lefflefo	Halisgage	
Pellonula vorax Gunther	PV				
Sardinella maderensis (Lowe)	SA	Sardine	Yaboyo	Yaboi	

(continued)

APPENDIX 3. (Continued).

Family and Scientific Name	Code	English	Mandinka	Wollof	Pulaar
CYNOGLOSSIDAE					
Cynoglossus senegalensis (Kaup)	CY	Solefish		Lambassesewo	
CYPRINIDAE					
Barilius senegalensis Steindachner	BS				
Labeo coubie Rupell	LC				
Labeo senegalensis Valenciennes	LS				
Labeo toboensis Svennson	LT				
Labeo spp.	LX		Dolla/Kulungdomo		Djandere
CYPRINODONTIDAE					
Aplocheilichthys normani Ahl			Senola	Tumbulan	
DASYATIDAE			Kotoro	Tumbulan	
Dasyatis margarita (Gunther)	DM	Ray			
Dasyatis spp.	DX	Ray			
DISTICHODONTIDAE					
Nannocharax ansorgei Boulenger	NA				
ELEOTRIDAE					
Bostrychus africanus Steindachner	BO		Yoso	Yoss	
Kribia nana (Boulenger)	KN				
ELOPIDAE					
Elops lacerta Valenciennes	EL	Ninebone	Ginjano/Salango	Nginyan/Ngeneyaan	
Elops senegalensis Regan	ES	Ninebone	Salango	Wallidor/Ngeneyaan	
EPHIPPIDAE					
Drepane africana (Osorio)	DA	Sadefish	Badabandingo	Tapandarr	
EXOCOETIDAE					
Hyporhamphus picarti (Valenciennes)	HP	Half beak?			

(continued)

APPENDIX 3. (Continued).

Family and Scientific Name	Code	English	Mandinka	Wollof	Pulaar
GOBIIDAE					
Periophthalmus papilio (Bloch)	PP	Gobie?			
Porogobius schlegeli (Gunther)	PG				
GYMNURIDAE					
Gymnura micrura (Block and Schneider)	Gm	Ray			
HEPSETIDAE					
Hepsetus odoe (Bloch)	HD	Tigerfish?	Sanko		Seguelli
HETERENCHELYDAE					
Pythonichthys macrurus (Regan)	PY	Eel			
MALAPTERURIDAE					
Malapterurus electricus (Gmelin)	ME	Electric catfish		Waga	Madjie
MOCHOEIDAE					
Synodontis annectens Boulenger	SY	Upsidedown catfish	Kosso	Gangue/Kockricko	
Synodontis batensoda Rupell	SB	Upsidedown catfish	Kosso	Gangue/Kockricko	
Synodontis gambiensis Gunther	SG	Upsidedown catfish	Kosso	Gangue/Kockricko	
Synodontis membranaceus St. Hilaire	SD	Upsidedown catfish	Kosso	Gangue/Kockricko	
Synodontis omias Gunther	SD	Upsidedown catfish	Kosso	Gangue/Kockricko	
Synodontis spp.	SX	Upsidedown catfish	Kosso	Gangue/Kockricko	
MONODACTYLIDAE					
Psettias sebae (Cuvier)	PK	Angel fish?			
MORMYRIDAE			Dacouro		
Brienomyrus niger (Gunther)	BR	Elephant fish			
Hyperopisus occidentalis (Gunther)	HO	Elephant fish			
Marcusenius senegalensis (Steindachner)	MS	Elephant fish			
Marcusenius spp.	MX	Elephant fish			
Mormyrops breviceps Steindachner	MB	Elephant fish	Nalo	Nali	Fadourou/Barsou
Mormyrops deliciosus (Leach)	MD	Elephant fish	Nalo	Nali	Fadourou/Barsou
Petrocephalus bovei (Valenciennes)	PH	Elephant fish			
Petrocephalus simus (Sauvage)	PC	Elephant fish			
Pollimyrus isidori (Valenciennes)					

(continued)

APPENDIX 3. (Continued).

Family and Scientific Name	Code	English	Mandinka	Wollof	Pulaar
MUGILIDAE					
Liza falcipinnis (Valenciennes)	LF	Mullet	Tambajanmgo	Kaakanjah	
MYLIOBATIDAE					
Petromylaeus bovina (St. Hilaire)	PT	Skate?			
NOTOPTERIDAE					
Papyrocranus afer (Gunther)	PF				
OPHICHTHIDAE					
Pisodonoplus semicinctus (Richardson)	PD	Eel			
POLYNEMIDAE					
Galeoides dacadactylus Bloch	GD	Shine nose	Chekema/ Nalidacoro/ Nakako	Chekem	Ndeleau/ Bangalinalo
Pentanemus quinquarius (Linnaeus)	PE		Burama	Ngorreekim	
Polydactylus quadrifilis (Cuvier)	PQ	Threadfin	Kujalo	Kujali	
POLYPTERIDAE					
Polypterus lapradei Steindachner	PL	Bichir	Pata Kuto/Kambono		Boucal
Polypterus palmas Ayres	PR	Bichir	Pata Kuto/Kambona		Boucal
POMADASYIDAE					
Brachydeuterus auritus (Valenciennes)	BA				
Plectorhynchus macrolepis (Boulenger)	PM				
Pomadasys jubelini (Cuvier)	PJ		Sompato/Jungkandomo	Sompat	
Pomadasys peroteti (Cuvier)	PP		Sompato/Jongkandomo	Sompat	
RHINOBATIDAE					
Rhinobatos cemiculus St. Hilaire	RC	Skate?			
SCHILBEIDAE					
Schilbe mystes (Linnaeus)	SM	Catfish	Seeba/Fanjo	Khele	Nguello

(continued)

APPENDIX 3. (Continued).

Family and Scientific Name	Code	English	Mandinka	Wollof	Pulaar
SCIAENIDAE					
Fonticulus elongatus (Bowdich)	FE	Drum	Taroro	Jottoh	
Pseudotolithus brachygnathis Bleeker	PB	Cassavafish	Sindoe/Tabasewo	Beyo/Ngouka	
Pseudotilithus senegalensis (Valenciennes)	PS	Ladyfish	Mbosoro	Tonon	
Pteroscion peli (Bleeker)	TP	Drum			
Umbrina cirrosa (Linnaeus)	UC	Drum			
SCOMBRIDAE					
Scomberomonus tritor (Cuvier)	ST				
SERRANIDAE					
Epinephelus aeneus (St. Hilaire)	EA	Grouper	Choffo	Choff	
SPHYRAENIDAE					
Sphyraena guachancho (Cuvier)	SP	Barracuda	Wangkango	Sedda	
Sphyraena sphyraena (Linnaeus)	SH	Barracuda			
SOLEIDAE					
Synaptura lusitanica Capello	SL	Flatfish			
Vanstraelenia chiropthalmus (Regen)	VC	Flatfish			
TETRAODONTIDAE			Doudou		Doudou
Ephippion guttifer (Bennett)	EG	Puffer fish			
Lagocephalus laevigatus (Linnaeus)	LL	Puffer fish			
TORPEDINIDAE					
Torpedo marmorata Risso	TM	Skate			
TRIAKIDAE					
Galeorhinus galeus (Linnaeus)	GG?	Shark			
TRICHIURIDAE					
Trichiurus leptunis Linnaeus	TL				

APPENDIX 4. Methods used for calculation of fish standing crop and annual yield based upon direct measurement, values reported in the literature, primary productivity, morphoedaphic index, total phosphorus, and catch-assessment data. Values for parameters used in these calculations are listed in Appendix 5.

CALCULATIONS FOR STANDING CROP (KG/HA)

Direct measurement (DM)

Two methods used to sample fish during our studies on the Gambia River provided direct, single-point estimates of fish standing crops (SC): trawling and block-netting. A description of trawling and blocknetting gear used in this study appears in Appendix 1; dimensions of area trawled were calculated in Bimber et al. (1984).

1. Benthic trawls - standing crop was calculated from benthic trawl catches using the following equation:

$$SC = \frac{C}{kA} = 3.3\ C \qquad (1)$$

where:

SC = estimated standing crop per hectare (kg/ha);
k = gear catch-efficiency constant (could range from 0 (0% fish caught per area swept) to 1 (100% fish caught per area swept); we assumed trawl caught all fish in the area swept (k = 1)
C = benthic trawl catch (kg);

and:

A = area fished (ha);
= duration of fishing (min) x tow speed (m/min) x width of area trawled (m);
= 10 min x 83 m/sec -x 3.5 m;
= 3,000 m^2;
= 0.3 ha.

2. Pelagic trawls - standing crop was calculated from pelagic trawls catches using the following equation:

$$SC = \frac{C/V \times TV}{k(TA)} = \frac{C/2{,}000 \times TV}{TA} \qquad (2)$$

where:

SC = estimated standing crop per hectar (kg/m^2 converted to kg/ha);
k = gear catch-efficiency constant (we assumed k = 1, see note for Item 1 above)
C = pelagic trawl catch (kg);
TV = total water volume (m^3);
TA = total area (m^2);

and:

V = volume fished (m^3);
= duration of fishing (min) x tow speed (m/min) x area trawled (m^2)
= 10 min x 83 m/min x 2.45 m^2
= 2,000 m^3.

(continued)

Block nets - standing crop was estimated by dropping block nets at the point where water exited a bolon or floodplain during ebb tide. Nets were raised during incoming tide, dropped at high slack tide, and rotenone was applied to the contained area. The floodplain drained completely and all fish were recovered. Water remained in the bolon and it was estimated that only 50% of the standing crop of fish was recovered. The dimensions of all areas fished were measured. Standing crop for floodplain block nets was calculated as follows:

$$SC = \frac{C}{kA} = \frac{C}{A} \qquad (3)$$

where:

SC = estimated standing crop per hectar (kg/ha);
k = gear catch-efficiency constant (we assumed all fish trapped were caught, therefore k = 1)
C = catch (kg);
A = area fished (ha).

and for bolon block nets standing crop was calculated as:

$$SC = \frac{C}{kA} = \frac{C}{0.5A} \qquad (4)$$

where:

k = 0.5 (we estimated that only one-half or 50% of the fish trapped and killed were recovered)

Literature (LIT)

Measurements or values for standing crop reported for similar river systems were cited when applicable to the Gambia River system or proposed reservoirs.

CALCULATIONS FOR ANNUAL YIELD (KG/HA/Y)

Primary production (PP)

Primary production (μg C/L/h) was measured during field experiments conducted *in situ* during our 1983-1984 studies on the Gambia River. Estimates of fish yield were calculated based upon the regression equation developed by Melack (1976) for eight African Lakes:

$$\log10\ FY = 0.91 + 0.113\ PG \qquad (5)$$

where:

FY = fish yield (kg/ha/yr);
PG = mean gross photosynthesis ($gO_2/m^2/d$).

(continued)

Morphoedaphic index (MEI)

Fish yield was predicted from an MEI calculated with equations presented in Marshall (1983) which used conductivity as a measure of MEI. Reservoir conductivity was predicted from our measurements of river conductivity by:

$$\log10\ KL = 0.754 + 0.734\ \log10\ KR \qquad (6)$$

where:

KL = reservoir conductivity (μmhos/cm);
KR = river conductivity (μmhos/cm).

Morphoedaphic index (MEI) was calculated from conductivity as follows:

$$MEI = \frac{KL}{\bar{z}} \qquad (7)$$

where:

$\bar{z}$ = mean reservoir depth (m).

Finally, fish yield was calculated from MEI using the following equation:

$$Y = 23.281\ MEI^{0.447} \qquad (8)$$

where:

Y = fish yield (kg/ha/yr).

Total phosphorus (TP)

Fish yield was estimated from our measurements of total phosphorus using the equation presented in Marshall (1983):

$$Y = 0.792 + 0.072\ TP \qquad (9)$$

where:

Y = fish yield (kg/ha/yr);
TP = total phosphorus (μg/L).

Catch Assessment Survey Data

Annual yield was estimated from total annual catch of a given taxa recorded by the Fisheries Department (Ministry of Water Resources and Environment, Banjul, The Gambia) during their catch-assessment surveys on the Gambia River. These surveys are described in detail by Dorr et al. (1983) and Josserand (1984). Four estimates were developed assuming that annual fishery yield constituted 100%, 50%, 10%, and 1%, respectively, of maximum sustainable yield (MSY) - MSY has not been established for the Gambia River.

APPENDIX 5. Values for depth, area, volume, salinity or conductivity, total phosphorus, and primary productivity used to calculate fish yields from ecological zones of the Gambia River, West Africa. N/D = no data.

River zone	Parameter[1]	Hydrological stage of river: Rising water	Peak flood	Declining water	Low water
Lower estuary	D	5.3	5.5	5.3	5.0
	A	411	411	411	411
	V	21.8	22.6	21.8	20.6
	S	33.01	32.38	33.48	34.07
	TP	15.13	14.17	17.58	35.81
	PP	6.158	6.555	4.947	2.402
Upper estuary	D	10.5	11.0	10.5	10.0
	A	229	229	229	229
	V	24.0	25.2	24.0	22.9
	S	13.67	0.23	2.15	11.21
	TP	6.50	23.79	24.63	11.27
	PP	9.232	0.054	0.169	11.251
Lower river	D	5.5	6.0	5.5	5.0
	A	50	50	50	50
	V	2.8	3.0	2.8	1.3
	C	89.21	50.61	49.68	51.58
	TP	12.25	7.68	8.75	6.87
	PP	8.658	0.937	0.993	1.939
Upper river	D	1.0	2.0	1.0	0.5
	A	15	15	15	15
	V	0.2	0.3	0.2	0.1
	C	91.08	41.81	36.34	51.75
	TP	N/D	16.68	5.07	8.60
	PP	N/D	0.196	3.718	4.292
Head-waters	D	0.5	1.0	0.5	0.5
	A	4	4	4	4
	V	0.02	0.04	0.02	0.02
	C	70.00	N/D	30.00	45.00
	TP	N/D	N/D	N/D	N/D
	PP	2.138	N/D	0.673	2.004

1 Values for mean depth (D - m), salinity (S - ppt), conductivity (C - μmhos/cm), total phosphorus (TP - μg/L), and primary productivity (PP - mg02/m^2/d) were calculated from our field data. Values for river area (A - ha x 10^2) were calculated by planimetry for lower and upper estuary reaches of the river; river areas were estimated for the lower and upper river reaches and the headwaters. River volumes (V - m^3 x 10^8) were calculated by multiplying area times mean depth. Conductivity of saline water is nearly a direct reflection of its salinity, and therefore was not measured in the estuarine portions of the river.

APPENDIX 6. Values for depth, area, volume, conductivity, total phosphorus, and primary productivity used to calculate fish yields from reservoirs proposed for the Gambia and tributary rivers, West Africa. N/D = no data.

Reservoir	Parameter[1]	Hydrological stage of river: Rising water	Peak flood	Declining water	Low water
Balingho	D	3.1	4.1	3.1	2.1
	A	498	701	498	294
	V	12.35	13.39	12.35	11.31
	C	89.21	50.61	49.68	51.58
	TP	12.25	7.68	8.75	6.87
	PP	8.658	0.937	0.993	1.939
Kekreti	D	7.0	10.3	7.0	3.7
	A	188	341	188	34
	V	18.14	35.00	18.14	1.28
	C	91.08	50.61	49.68	51.58
	TP	N/D	16.68	5.07	8.60
	PP	N/D	0.196	3.718	4.292
Kouga-Foulbe	D	6.0	12.0	6.0	3.0
	A	19	38	19	10
	V	2.25	4.50	2.25	1.13
	C	70.00	N/D	30.00	45.00
	TP	N/D	N/D	N/D	N/D
	PP	2.138	N/D	0.673	2.004
Kanka-koura	D	8.0	16.0	8.0	4.0
	A	4.2	8.3	4.2	2.1
	V	0.6	1.3	0.6	0.3
	C	70.00	N/D	30.00	45.00
	TP	N/D	N/D	N/D	N/D
	PP	2.138	N/D	0.673	2.004
Kouya	D	21.0	42.0	21.0	10.5
	A	50	101	50	25
	V	21.37	42.74	21.37	10.69
	C	70.00	N/D	30.00	45.00
	TP	N/D	N/D	N/D	N/D
	PP	2.138	N/D	0.673	2.004

[1] Values for mean depth (D - m), total area (A - ha x 10^2), and total volume (V - m^3 x 10^4) are modified from those cited in Harza Engineering Company, International (1984) (personal communication, N. Schickedanz, Harza Engihneering, Chicago, Ill.). Depth, area, and volume of Balingho and Kekreti Reservoirs during rising and declining water were assumed to be one-half those of peak flood (or full capacity) values. Depth, area, and volume of Guinean reservoirs were estimated as percent peak flood (or full capacity) as follows: rising and declining water = 50%, low water = 25%. Values for conductivity (C - μmhos/cm), total phosphorus (TP - μg/L), and primary productivity (mg02/m^2/d) are those that were measured for corresponding areas of the river. In Guinea, measurements were made only in the vicinity of the Kouga-Foulbe Reservoir site; these measurements were used to represent values for the other two Guinean reservoirs.